Spring 1998

The Geomorphological History of an Alluvial fan Complex in Nelson County, Virginia

Melinda Ann Youngblood
Old Dominion University

THE GEOMORPHOLOGICAL HISTORY OF AN

ALLUVIAL FAN COMPLEX IN NELSON COUNTY, VIRGINIA

By

Melinda Ann Youngblood
B. S. May 1994, Old Dominion University

A Thesis submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE

GEOLOGY
OLD DOMINION UNIVERSITY
May 1998

Approved by:

Dr. G. Richard Whittecar
(Chairman)

Dr. D. A. Darby

Dr. J. H. Rule

ABSTRACT

The Geomorphological History of an
Alluvial Fan Complex in Nelson County, Virginia

Melinda Ann Youngblood
Old Dominion University, 1997
Director: Dr. G. Richard Whittecar

An alluvial fan complex blankets a portion of the Rockfish Valley in Nelson County Virginia, located along the eastern slope of the Blue Ridge Mountains. The seven-km^2 field area contains three mappable relict alluvial surfaces (Qf1, Qf2, and Qf3) and one modern surface (Qal), each of which is underlain by fluvial deposits dominated by greenstone and charnokite cobbles. The four surfaces were mapped according to topographic position and degree of stream dissection. Alluvial deposits underlying each surface were characterized using a 3-part clast weathering scale based on greenstone clast weathering rinds and using soil development criteria (clay content, Munsell colors, and total free iron in the argillic horizon). The highest surface remnants (Qf1) were the most weathered and dissected with very high clay contents (70-80%), very red soil matrix colors (10 YR to 2.5 YR), and highly weathered clasts. Fan surfaces of intermediate elevation and moderate dissection (Qf2) had high clay contents (60-70%), medium red-to-orange (2.5 YR to 7.5 YR) colors, and a combination of weathering rind types. The lowest relict surface (Qf3) contained little clay (10-30%) and mostly competent greenstone clasts.

Cluster and discriminant function analyses of the soil development and rock weathering data strongly support the mapping criteria used to distinguish the three relict alluvial surfaces. The clast weathering scale developed for this study provided especially

useful distinctions between different deposits. The strong separation of surfaces based upon the relative age criteria indicates fan surfaces were deposited during separate episodes widely spaced in time. Comparisons of these data with other sites suggest that Qf1 and Qf2 surfaces are "earliest Pleistocene or older", although the Qf1 surface is significantly older than Qf2, that Qf3 is late Pleistocene in age, and that Qal is the only large fluvial surface now active. Previous workers suggested that multiple surfaces on an alluvial fan complex directly across the Blue Ridge in Augusta County, Virginia, resulted from a late Tertiary tectonic event followed by Quaternary climatic changes. Although the fan sediments in the present study area are not well dated, the geomorphic evidence also supports the interpretations that these tectonic and climatic events also induced alluvial fan formation in the Rockfish Valley.

ACKNOWLEDGMENTS

Those people who have walked before me only know the fulfillment of the master's thesis. I have learned many truths about myself and geology through this experience. My mentor, Dr. Rich Whittecar, made the last three years irreplaceable because of his excitement and drive for geology and life. My sincere thanks go to him. I would like to thank other faculty and staff in the geology program for ignoring me during my bad days and cheering me on during the good days, especially, my other committee members, Dr. Joe Rule and Dr. Dennis Darby, who offered advice during different aspects of the study.

Field work for this project was partially supported by the geology program. I would like to thank my fellow students and friends who I convinced to do field work with me: Roseanne Hinshaw, Jason Shelton, Vladimier Ispatolov, Dan Hollaway, Adam Karst, Scott Eaton, and Claire Conley. Don Woodruff was invaluable in helping me with computer design throughout the study and getting the final document together and printed. I thank him for his continued support and putting up with my unstable attitude. Finally, my dear thanks to my parents, Fred and Virginia Youngblood. Their determination and assistance both emotionally and financially was well appreciated.

I would like to dedicate this manuscript to my late grandmother, Edith Presley. Her loss during the early stages of this study showed me my will to achieve wonderful things and experience life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Alluvial fans blanket many of the footslopes in the Blue Ridge Mountains of Virginia. A relatively large set of broad, sloping alluvial deposits exist in the Rockfish Valley of Nelson County, Virginia. Recent geomorphological research elsewhere in the Blue Ridge Province has used similar alluvial fans to understand the role of climatic and tectonic influences in the Quaternary history of regional landscape (e. g. Kochel, 1990; Mills and Allison, 1995; Ritter et. al., 1995; Whittecar and Ryter, 1992; Whittecar and Duffy, in press). In order to understand the history of geomorphic processes on the fans in Nelson County, this investigation uses soil and rock weathering criteria to map alluvial surfaces. The spatial distribution of different fan surfaces and statistical analyses of soil-profile development and weathering of Catoctin greenstone clasts indicate the mosaic of alluvial deposits in this area is more complex than previously recognized (e. g. Bartholomew, 1977). Although weathering rind and soil development criteria have been used elsewhere to establish the relative ages of fan surfaces and to compare these surfaces to dated landforms and deposits (e. g. Markewich et al. 1987, 1989; Whittecar and Ryter, 1992; Mills and Allison, 1995; Whittecar and Duffy, 1998), previous studies have not used the distinctive weathering pattern of clasts derived from the widespread Catoctin greenstone. The purpose of this project is to decipher the geomorphic history of this area in an attempt to determine the influence of climate and/or tectonic changes upon fluvial erosion and deposition during the Quaternary and to improve the comparability of relative age criteria used on fans in different areas of the Blue Ridge.

The Journal of Geology was used as the journal model for this thesis.

Description of Study Area

The study area lies at the western limits of the Piedmont Province of Virginia in Nelson County. The alluvial fans extend to the northeast, covering approximately seven square kilometers from Wintergreen cemetery to Camp Monocan in the Sherando and Greenfield quadrangles (Figure 1). The alluvial fans within the study area extend in a northerly direction from approximately 274 meters (900 ft) elevation at the mountain front and descend to between 213 to 198 meters (700 to 650 ft) elevation at their distal margins. The site is bounded to the northwest by the Blue Ridge, to the southwest by Spruce Creek, to the southeast by Virginia Route 151 and to the northeast by county Route 618.

This site was selected for several reasons. Fortunately, the alluvial complex in this portion of the Rockfish Valley is very widespread compared to most others in the Blue Ridge (Kochel, 1987). Soil scientists preparing drain field reports for the Health Department have done considerable work recently in this area. In addition, a study on the opposite side of the ridge in Augusta County proposed a combination of climatic and tectonic events to form similar alluvial fans from different source rocks (Whittecar and Duffy, 1998). Thus, this new study area provides a test of the effectiveness of the proposed geomorphic events. The next two sections will discuss the bedrock geology of this area, and previous interpretations of the Nelson County fans and alluvial fans in other settings.

Bedrock Geology

Rocks in the Blue Ridge Mountains in and around the study area lie within the Precambrian/Cambrian Catoctin Formation, the Precambrian Swift Run Formation, the

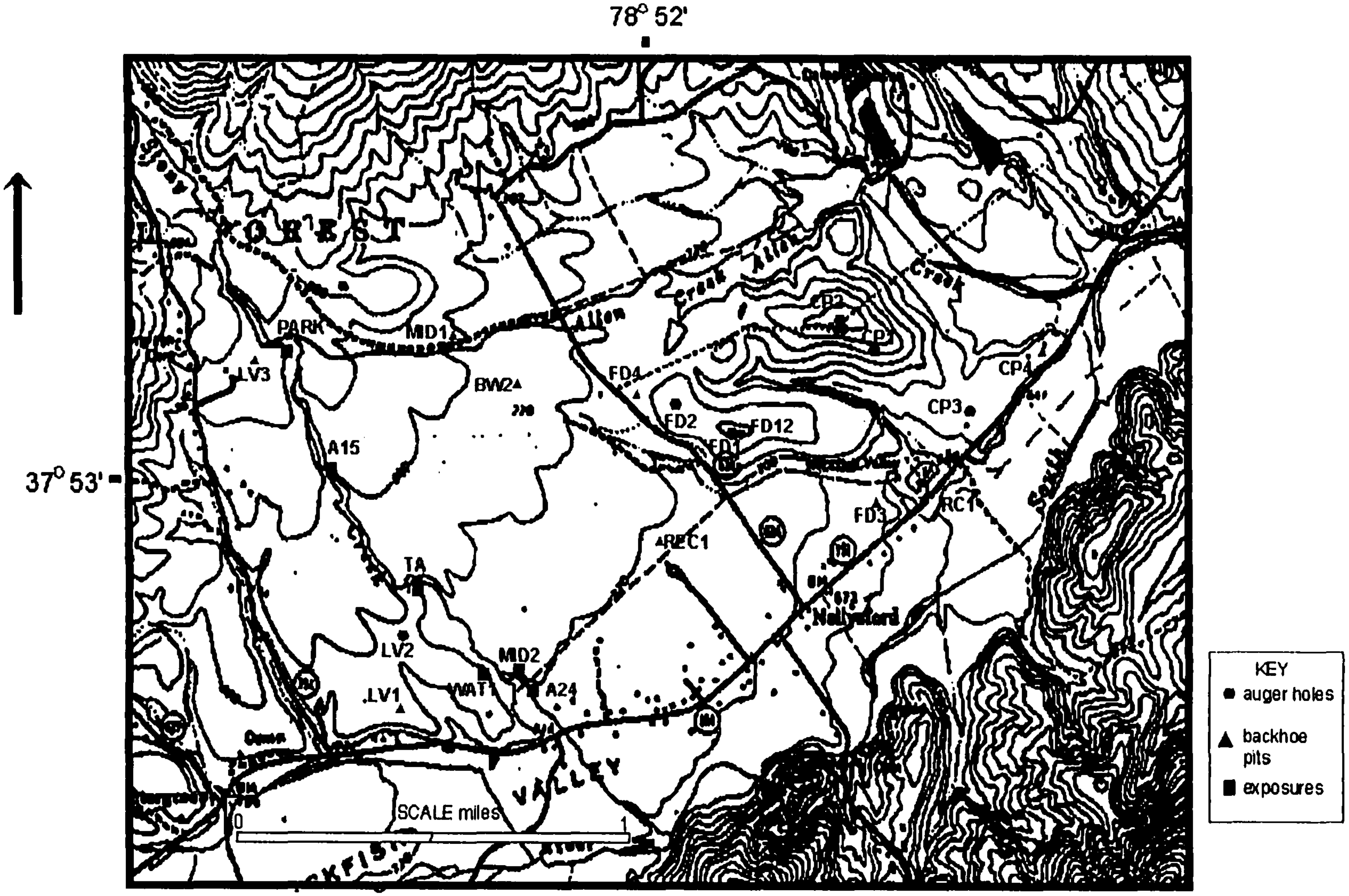


Figure 1. Topographic map of field area, Nelson County, Virginia. The field area overlaps the Greenfield and Sherando 7.5-minute quadrangles. Also shown here are sites used for stratigraphic, soil development , and rock weathering analyses.

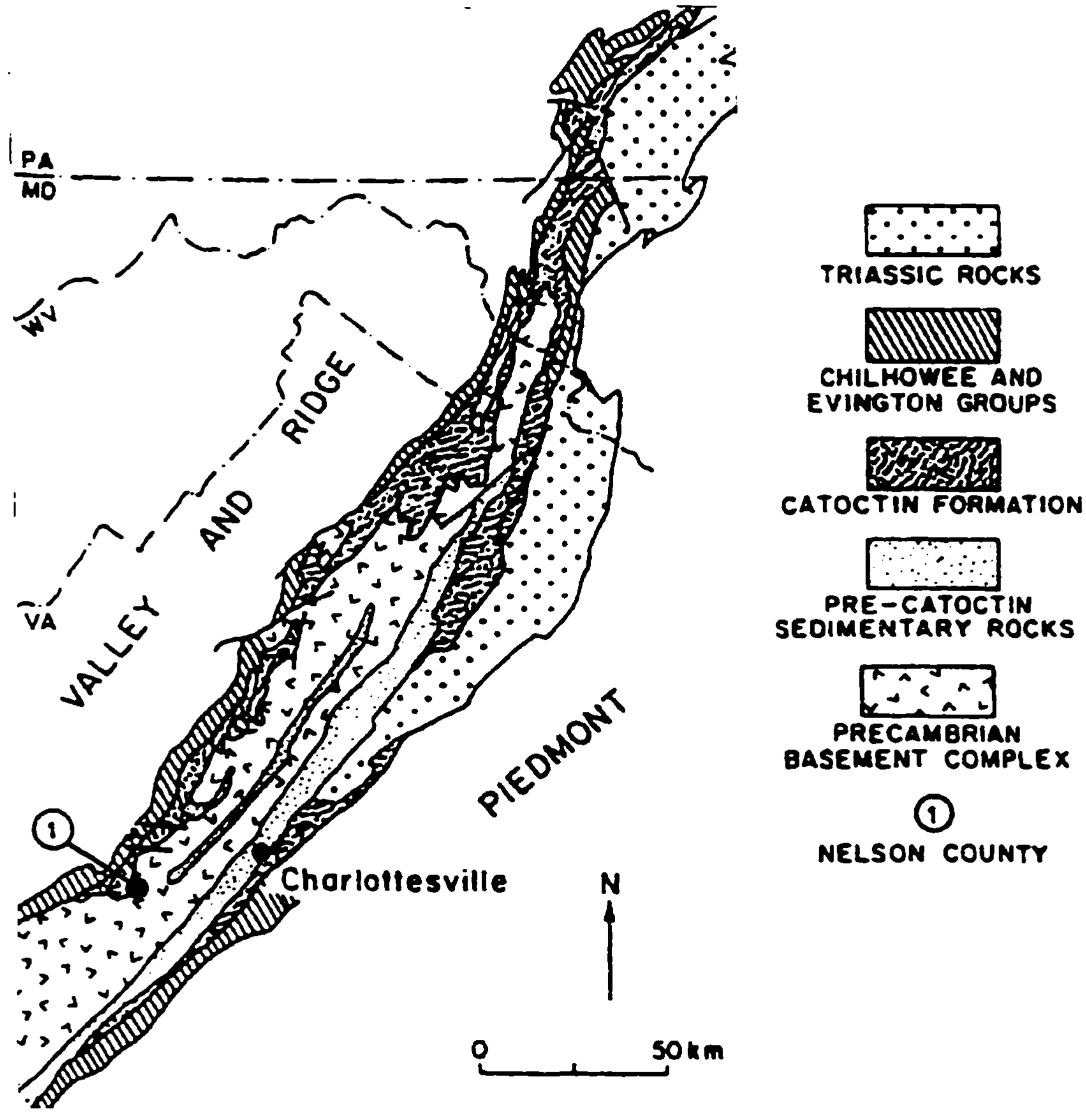


Figure 2. Geologic map of field area. Nelson County is located in the Blue Ridge province where Precambrian basement rock dominates in the east and Catoctin Formation outcrops to the west (from Badger, 1993).

Precambrian Pedlar Formation, and the Precambrian Layered Granulite Gneiss Formation.

The Catoctin Formation supports the crests of the Blue Ridge in the area (Figure 2). This meta-volcanic unit consist mostly of massive, gray-green metamorphosed basalt, greenstone and epidosite, composed of albite, chlorite, epidote, and actinolite with numerous thin beds of tuff-phyllite, siltstone phyllite, meta-arkose, and arkosic-metasandstone (Bartholomew, 1977; Hack, 1982; Badger, 1993). The stratigraphic thickness of this formation is approximately 600-to-760 m, but it is locally deformed and may be more than 1000 m thick (Gathright, 1976; Bartholomew, 1977).

The Swift Run Formation metaconglomerate grades upwards into the Catoctin Formation and rests unconformably on the Pedlar Formation in most of the area (Figure 3). Where the metaconglomerate is absent, the Catoctin lavas rest unconformably upon the Blue Ridge Precambrian Basement Complex (Badger, 1993). The principal lithologies are slightly foliated, coarse grained, conglomeratic quartzose metasandstones and sandy, lithic quartz-pebble metaconglomerate (Bartholomew, 1977).

The Pedlar Formation charnokite outcrops immediately southwest of the field area and intrudes the layered granulite facies. This Greenville-age, massive pyroxene-bearing granite is primarily uniform but contains several lenses of Layered Granulite Gneiss (Bartholomew, 1977). The Layered Granulite Gneiss Formation is distinguishable from the massive charnokite by granoblastic texture, finer grain size, and different relative proportions of the major granulite-facies minerals, e. g. biotite (Bartholomew, 1977).

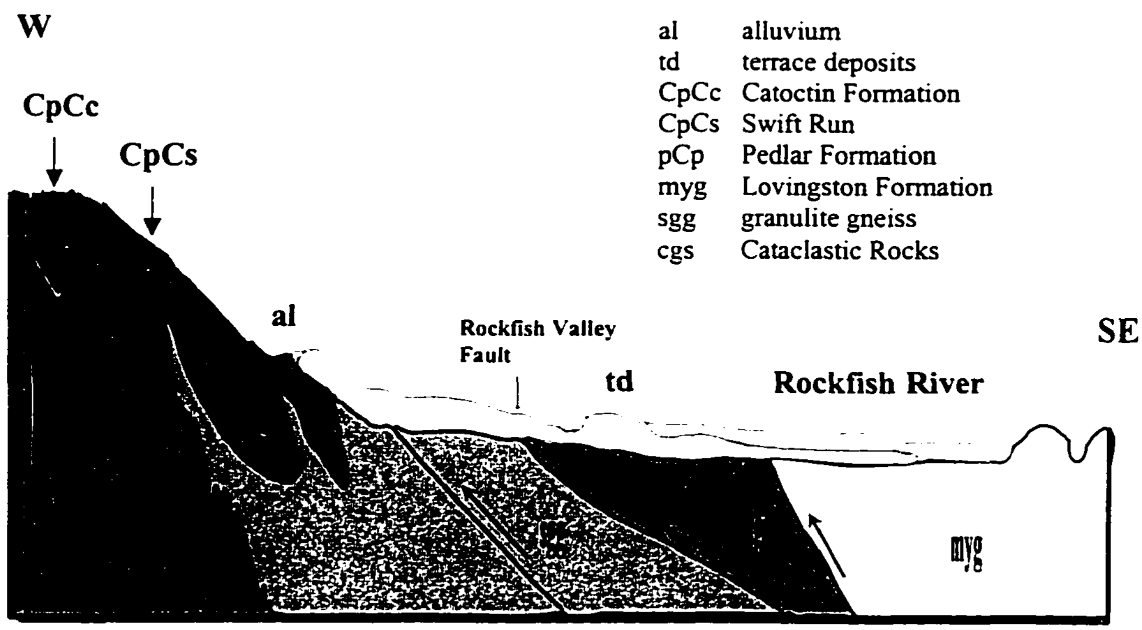


Figure 3. Cross-section of field area (from the SE corner of the Sherando 7.5 minute Quadrangle, Bartholomew, 1977). Bartholomew recognized two Quaternary age deposits, al and td. The fans in the study area lie in the same stratigraphic and geomorphic positions as td and al.

Deposits of alluvium cover the majority of the field site, most, if not all, of which originate from the Stony Creek drainage. Two previously mapped Quaternary units, terrace (td) and alluvium (al) (Bartholomew, 1977), extend down Stony Creek valley and stretch across the Rockfish Valley lowland from 311 meters (1020 ft.) near the Blue Ridge to 195 meters (640 ft.) elevation within the proximity of the Rockfish River. Pebbles, cobbles, and boulders of quartz, greenstone, charnokite, gneiss and granite dominate the clasts in the terrace deposits, supported by a yellowish-brown to reddish-brown matrix of sand, silt, and clay. Alluvium (al) of Bartholomew (1977) includes sandy floodplain deposits of the Rockfish River and coarse stream deposits of Stony Creek.

Only Precambrian and Paleozoic faults and folds are recognized within the field area (Figure 3) (Bartholomew, 1977). The Paleozoic age structures exhibit several periods of tectonism. Relatively old thrust faults along the Rockfish Valley Fault cut the Pedlar Formation (Wayne and Sinha, 1992) and were folded with the Catoctin and Swift Run Formations. Less intense folding close to the Rockfish Valley fault and younger Paleozoic thrust faults exist. Undeformed terrace and alluvium deposits overlie all of these structures.

Previous Studies

Geomorphology and Sedimentology of fans. Many geologic studies focus upon bedrock and regard regolith as only a "cover". For example, Bartholomew (1977) recognized the Quaternary system in the Greenfield and Sherando quadrangles as a well-dissected bajada (alluvial fan complex) but separated these sediments into only two map units - terrace deposits (td) or alluvium deposits (al).

Geologic maps that provide greater detail about regolith can illustrate many aspects of the recent geologic history and future land use potential of an area. Maps and analyses of alluvial fans commonly differentiate between deposits formed by various processes and also distinguish fan units of different age, contributing much to our understanding of the geomorphic history of the Blue Ridge region.

Many researchers report alluvial fans may be constructed by many processes including debris flows, fluid gravity flows, and/or sheetfloods (Blair and McPherson, 1994; Kim, 1995). Failure to identify the flow type has led to significant scientific misunderstanding and erroneous remedial practices. For example, channelization for debris flows is ineffective because channels can quickly become blocked, causing subsequent surges to flow in new directions (Costa, 1988). The characteristic of the sediment in the entrained flow creates some variation in flow deposits. Natural distinctions useful in distinguishing deposits left by debris flow, hyperconcentrated flow, and river deposits can be based on morphology, hydraulic processes, and sedimentary processes and facies assemblages.

Alluvial fans deposited by debris flows exist in many places within the Blue Ridge (e.g. Kochel and Johnson, 1984; Kochel, 1987; Mills, 1987; Simmons, 1988; Kochel 1990; Whittecar and Ryter, 1992). These fan surfaces are topographically constrained by narrow basin interfluves on steep hillslopes and considered primarily aggradational deposits. Laminar flow regimes and sediment concentrations of greater than 70% by weight are characteristics typical of debris flow deposits. This flow regime creates deposits consisting of matrix-supported coarse clasts in massive beds with extremely poor sorting and reverse grading (Costa, 1988). Landforms typical of debris flow deposits are U-shaped channels, marginal levees and terminal lobes.

In comparison, alluvial fans dominated by fluvial activity along the Valley and Ridge province are topographically unconstrained and have broad widespread margins. Turbulent flow regimes are characteristic of these flow types with sediment concentrations up to 40% by weight (Costa, 1988). Deposits usually consist of stratification, cross-bedding, imbrication, and cut-and-fill sedimentary structures. Various types of bars, fans, sheets and splays are common landforms found in stream flow deposits. Fans deposited by braided streams can be found along the western flank of the Blue Ridge. These large, unconstrained fans contain clast-supported boulder-to-cobble size quartzite clasts with fining upward sequences, imbrication, and channel fill deposits (Kochel and Johnson, 1984; Mills, 1987; and Whittecar and Duffy, 1993).

Alluvial fans deposited by hyperconcentrated flow types are developed in areas of uniformly resistant rocks, tend to be small and have irregular shapes (Kochel, 1990). The hydraulic processes which create these deposits are approximated as moderately turbulent to laminar flow regimes with sediment concentrations between 40 and 70 % by weight (Costa, 1988). These transitional deposits are difficult to identify and are poorly understood.

The previous studies of alluvial surfaces in Nelson County indicate intermediate size fans in comparison to those dominated by debris flow or fluvial activity. The underlying deposits that make-up these surfaces contain poorly sorted, matrix-supported, cobble-to-boulder size debris. Inverse grading of boulders has often been observed in

Nelson County fans as well as other areas along the Blue Ridge, with largest clasts appearing near the fan surface (Kochel and Johnson, 1984). The alluvial surfaces there share characteristics of both debris-dominated and fluvial-dominated fan complexes.

Debris-avalanches caused by large rainstorms associated with tropical air masses, such as Hurricane Camille, were considered the principal transport mechanism for much of the material in the Quaternary alluvium and terraces in the study area (Bartholomew, 1977). Hurricane Camille moved east north-eastward across Nelson and Augusta Counties on August 19-20, 1969, dumping 27 inches of rain in less than 8 hours. Schwarz (1970) reported torrential rains drenched the eastern slopes of the Blue Ridge and were responsible for this natural disaster, the worst known in Virginia. Debris avalanches, landslides, and flooding in the Tye and Rockfish river basins caused extensive material damage and loss of human life (Bartholomew, 1977). These rains allowed boulder-to-clay sized materials to be transported from the tops of the mountains down to the alluvial fans and floodplains. These floods also stripped and channeled some floodplains and eroded valley walls. The slides were most numerous on mountainsides underlain by the Lovingston Formation (Virginia Division of Mineral Resources, 1969; Webb, Nunan, and Penley, 1970). However, few slides occurred on the Pedlar charnokites and Catoctin metasediments (Peatross, 1986) which dominate the underlying bedrock in the field area.

Soil Chronostratigraphy. Very few soils and strata in Appalachian regolith contain organic material usable for radiocarbon dates. Thus, several studies in the region attempted to establish the relative ages of Quaternary deposits by using various measures of soil profile development criteria and clast rind thickness. The best relationship between absolute ages and these relative weathering features was established by Markewich et al. (1987) on dated Coastal Plain deposits in Maryland and Virginia. The most useful soil development criteria recognized for distinguishing the relative ages of Neogene sediments and surfaces were clay accumulation (percentage of clay in the less than 2 mm fraction), maximum redness (Munsell hue), and argillic horizon thickness. Soil hue values and B horizon thickness from Coastal Plain sediments show clear progressions toward redder colors and greater thickness with increasing age (Figure 4) (Markewich et al., 1987; Howard et al., 1993).

Soils formed in quartz-rich, well-drained sediments in climatic settings similar to eastern Virginia and Maryland should be comparable to those described by Markewich et al. (1987). By comparing the argillic Bt horizon (e. g., thickness; hue; percent clay; etc.) of soils on well-drained fans derived from Antietam quartzite ridges with the dated deposits of the Coastal Plain (Markewich et al., 1987), "order of magnitude" age estimates were determined for the fan surfaces (Whittecar and Duffy, in press). At least three mappable fan deposits exist in Augusta County (Figure 5) with the oldest (F1) gravels containing badly decomposed quartzite cobbles. These gravels were as weathered as the Pliocene-Miocene (?) Bon Air gravels on the Coastal Plain. The somewhat younger F2 fan gravels were more weathered than the Bacons Castle gravels, which had been dated as 2.1 to 2.3 million years old, and the youngest (F3) gravels were nearly unaltered. The F2 and F3 deposits were multiple fills that overflowed valleys carved into the very thick and extensive F1 deposits and apparently could have formed during a series of many short episodes. Therefore the oldest fans (F1) were related to a major

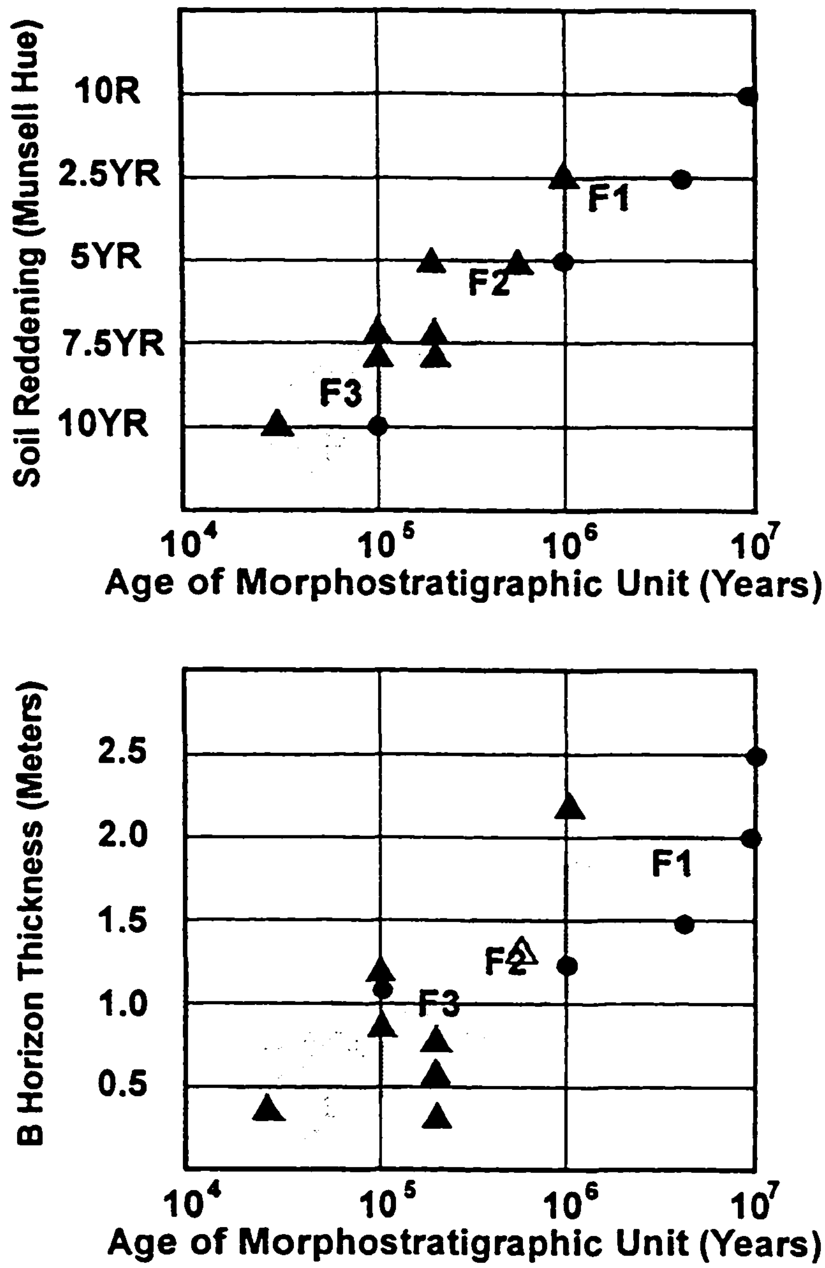


Figure 4. Graphs of B horizon soil color and thickness from the soils on Coastal Plain terraces. The diagram demonstrates B horizon thickness and soil hue versus age of unit. Markewich et al. (1987) established the best relationship between absolute ages and relative weathering features (rubbification and thickness) in the argillic horizon. Data are from Virginia and Maryland reported by Markewich et al. (1987, circles) and Howard et al. (1993, triangles). Shaded zones highlight trends of data (from Whittecar and Duffy, 1998).

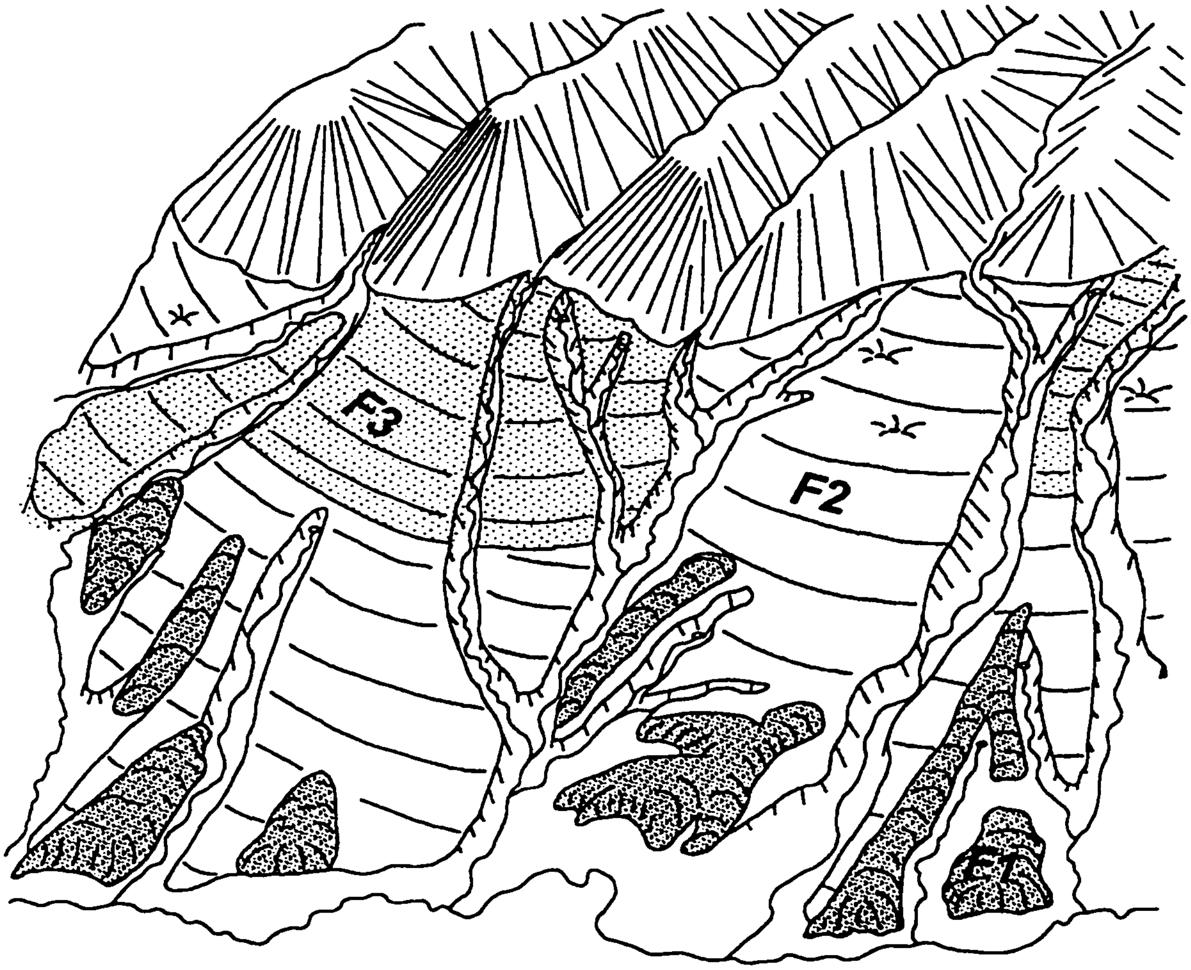


Figure 5. Physiographic map of alluvial fans in Augusta County, Virginia (from Whittecar and Duffy, in press). The oldest (F1) deposits contain highly weathered quartzite cobbles and are deeply dissected remnants. The intermediate (F2) deposits contain moderately weathered gravels with some dissection and the youngest (F3) deposits contain weakly weathered cobbles with few incised valleys (from Whittecar and Duffy, in press).

long- lasting event, such as the Miocene uplift event proposed by Poag and Sevon (1989), and the numerous younger fan surfaces (F2 and F3), to Quaternary climate changes (Whittecar and Duffy, in press).

Clay mineralogy has been used in the past to indicate soil age relationships between alluvial surfaces (Chittleborough and Walker, 1988; Gerrard, 1994). Kaolinite and gibbsite contents from dated soil chronosequences located along the Susquehanna River were compared to soils from alluvial surfaces in the Blue Ridge (Engel et al., 1996). No obvious trends of kaolinite and gibbsite were found between difference terrace elevations. However, old soils found in alluvial terraces from southeastern Australia had strong textural differentiation and were predominately kaolinite (Chittleborough and Walker, 1988). Clay mineral formation is a highly complex process and many factors must be considered (i.e. climate, parent material and time).

Soils that form in parent materials with appreciable amounts of clay and abundant easily weatherable mineral grains are more difficult to use for age comparisons. Numerous studies of soils on alluvial fans in the Appalachians derived from greenstones and amphibolites gave results of relatively high clay and iron content in soils on older, higher surfaces. However, it is difficult to make with comparisons to the quartzose Coastal Plain soils examined by Markewich et al. (1987) in order to assess the absolute ages of soils because of the high content of mafic minerals and clay in the parent materials on the alluvial fans (Whittecar and Ryter, 1992; Mills and Allison, 1995; and Woodward et al., 1994).

Clast weathering criteria have become an established relative age indicator for many types of regolith. Studies of surficial rinds on basaltic and andesite stones from dated glacial deposits clearly demonstrate that rock weathering processes are progressive and can be used to determine relative ages. In the western United States, although these processes start quickly, they slow with time and eventually reach a constant rate of change at 0.5 my (Colman, 1981; Colman and Pierce 1981). Whitehouse and Kneupher (1986), working on the Torlesse Sandstone in the Southern Alps, recognized that rind development involves two processes - rind growth inward and external surface losses. Rate of these two processes approach equality with time. Factors other than time influence rind growth, for instance, climate, lithology, grain size, and the degree to which the rocks have been buried or the geomorphic surface has been eroded (Kneupher, 1988). Mills (1995) suggested that clast weathering may provide a more consistent means of relative-age dating than soil characteristics because the weathering environment inside a clast is to some extent isolated from the soil environment and thus is less influenced by changes in soil-forming factors through time than is the soil matrix.

Classification schemes have been developed for clast weathering of some crystalline rocks in the Blue Ridge Mountains (Duffy, 1991; Mills and Allison, 1995). Whittecar and Ryter (1992) studied greenstone clasts in debris flow fans near Waynesboro, Virginia. Greenstones found in the upper 1 m of the upper, older fans were easily broken or dissected with a shovel and had an average rind thickness of 9.0 mm. Greenstone clasts found in the upper 1 m of lower, younger fans were very competent, resistant to breakage, and had only 4.3 mm rind thickness.

Thus, in order to make similar age determinations for fans along the eastern slopes of the Blue Ridge, one must develop weathering-age comparisons that are applicable to the numerous debris fans which contain large numbers of granitic or metabasalt clasts derived from the Pedlar, Catoctin, and other extensive Blue Ridge Formations. The present study area contains fans with these rock types. Also, it lies on the eastern margin of the same range studied by Duffy (1991), and thus may share its climatic and tectonic history. A geomorphic analysis of the multiple fan surfaces at this site will permit a future comparison of the weathering criteria in fans formed from different rock types.

Ideally, however, geomorphic studies of alluvial deposits need absolute dates. Few studies have been able to produce such information because of the lack of datable material within the deposits. Fan stratigraphy and radiocarbon dating have been used in the Davis Creek area in Nelson County to determine that the return periods for storm events, like Hurricane Camille, were 3,000 to 4,000 years during the present (Holocene) interglacial (last 10,000 years) (Kochel and Johnson, 1984). However, the general lack of organic material in fans within the field area and throughout the Blue Ridge makes radiocarbon dating impractical. Therefore, geomorphologists will need to establish the tectonic and climatic history of the Blue Ridge region by absolute dating of fan surfaces in another manner. New techniques based upon the accumulation of in-situ cosmogenic isotopes on stable surfaces (e. g. ^{10}Be accumulation studies) may prove to be very useful in this effort (Lal et al., 1997). In order to justify the expense of these future analyses, the relative age and geomorphic stability of datable sites needs to be established through understanding the processes which develop and destroy these surfaces.

Objectives and Significance of Research

The objective of this research is to decipher the depositional history of fans in this portion of Nelson County, Virginia. This research is significant because it may extend the usefulness of soil development criteria and clast weathering phenomena as relative age indicators on Blue Ridge fans. This work may also help to determine the influence of climate and/or tectonic changes on the alluvial fans. Fan formation processes may affect the residents living on active the alluvial surfaces. Geomorphic analysis of multiple fan surfaces in the study area will indicate which of these alluvial surfaces continue to build and erode today.

The goals of this research are these:

1. Map the alluvial fan surfaces that lie within the field area.
2. Describe and interpret the sedimentary structures within exposed alluvial fan deposits.
3. Determine relative ages of these deposits by a variety of weathering and soil development criteria.
4. Incorporate these data into an analysis of the processes, timing, and causes of alluvial fan deposition.

CHAPTER II

PROCEDURES

Field Methods

The distribution of fan surfaces possibly indicate which major processes effect an area (e. g., Whittecar and Duffy, 1992). In order to differentiate between high-level fan remnants and topographically lower fan surfaces, topographic breaks on the slopes were mapped initially using soil survey maps (1 : 1200 and 1 : 24000), aerial photographs (1 : 24000), and topographic maps (1 : 24000) and checked by field observations. The fan surfaces were divided into three relative-age groups on the basis of topographic position (e. g. high, medium, and low elevations above Stony Creek), and degree of dissection by small stream valleys. The combination of topographic maps, aerial photographs, soil survey data, and existing land use also gave clues to the relative ages of the sloping alluvial surfaces.

Two soil survey maps exist for this area. The Natural Resource Conservation Service (NRCS) report for Nelson County (1 : 24000) identified over 40 soil series (Table 1), correlated with map units defined elsewhere in the Appalachians (NRCS, in press). Wintergreen Inc., a resort development company, hired Harold Mathews (Mathews Soil Consultant, Inc.) to make soil maps in order to place septic tank drain fields on residential lots before construction. Septic tank drainfield suitability maps (1 : 1200) were made based upon landscape interpretation and three-to-five soil borings dug in each individual residential lot. Map units were based upon soil color, texture and percolation parameters. These soil types were classified on a scale of one-to-ten based on their suitability classes (Table 2).

Table 1. Soil series for Nelson County (from NRCS, in press).

Soil Series	Description
29B Lew silt loam	10 YR yellowish brown 7 to 15 percent slopes (60-65% rounded cobbles)
11A Craigsville loam	10 YR yellowish brown 0 to 2 percent slopes (65% rounded cobbles)
49C Unison loam	5 YR yellowish red to 2.5 YR red 7 to 15 percent slopes (30-40% gravels)
32E Minnieville loam	5 YR yellowish brown to 2.5 YR red 2 to 7 percent slopes (0-25% gravels)
52B Wintergreen loam	2.5 YR dark red 2 to 7 percent slopes (river terrace sediments)
52C Wintergreen loam	2.5 YR red (few rounded cobbles)

Table 2. Soil suitability classes from Mathews Soil Consultant, Inc.

Class	Description
1	Deep permeable soils developed from granite and schist. Good for use as drainfield sites using 3/4 acre lots.
2	Deep permeable soils developed from alluvial fan deposits. Good for use as drainfield sites using 3/4 acre lots. Deep wells or central water needed.
3	Deep to moderately deep permeable soils developed from micaschist and granordiorite. Fair to good for use as drainfield sites using 1 1/2 to 2 acre lots.
4	Deep moderately permeable soils developed from colluvial and alluvial deposits. Fair for use as drainfield sites using 1 1/2 to 2 1/2 acre lots.
5	Deep slowly permeable soils developed from granordiorite, greenstone, schist and colluvium. Fair to marginal for use as drainfield sites. Parcels of 2 1/2 to 3 acres are recommended.
6	Deep slowly permeable soils developed from colluvium. Marginal for use as drainfield sites. Parcels of 3 to 5 acres are recommended.
7	Deep permeable to slowly permeable soils developed from residual and colluvial Piedmont material. Steep slopes are the dominant problem. Marginal for use as drainfield sites. "Estate sized" parcels will be needed.
8	Shallow steeply sloping soils which have a high percentage of surface rocks. Poorly suited for use as drainfields.
9	Deep wet to moderately wet soils developed from alluvial and colluvial sediments. Not recommended for use as drainfield sites.
10	Deep sandy and cobbley soils developed from creek alluvium. Not recommended for use as drainfield sites.

Soil maps proved most useful in identifying significant geomorphic boundaries now obscured by construction. For example, suitability classes # 2 and # 4 on Mathews map correspond to alluvium and terrace deposits described by Bartholomew (1977). In addition the description of soil colors and clay content in the map units assisted in determining relative age of alluvial surfaces. The different alluvial fan surfaces were correlated based on the soil feasibility classes and soil series. The Lew silt loam and Craigsville very cobbley loam correspond to suitability class # 2 and lower topographic fan surfaces. Unison and Minnieville loams predominately associate with suitability class # 4 and middle surfaces. Wintergreen loam associates with suitability class # 4 and high level surfaces. Topographic breaks on sloping surfaces were then delineated on Greenfield and Sherando 7.5 minute quadrangles maps and on nine-by-nine inch, stereo-paired, aerial photographs.

Land use in the study area also helped in determining the relative ages of the alluvial surfaces. Relatively old surfaces are located on hill tops or in densely wooded areas, some of which are now part of the second golf course in Stoney Creek subdivision. These areas are cultivated for farm use or used for cemeteries in areas outside the subdivision, because digging is much easier on old weathered surfaces. Younger surfaces are located in topographically lower areas and are much more cobbley than old remnant surfaces. In the Stoney Creek subdivision, much of the first golf course was originally built on these younger surfaces.

Weathering and soil development criteria were used to describe soils exposed in stream cuts, road cuts, and backhoe excavations (Figure 1). Techniques used followed those developed by Singer and Janisky (1986), Markewich et al. (1987, 1989), Retallack

(1988), Whittecar and Ryter (1992), Whittecar and Duffy (1993), and Mills and Allison (1995). Wintergreen Inc. granted permission for six backhoe pits for the purpose of this investigation. Pit locations were chosen in broad undissected remnants of fan surfaces that were accessible. Auger holes were used in areas where exposures were inaccessible or backhoe pits were not permitted. Based upon experience of previous workers (e. g., Whittecar and Ryter, 1992; Whittecar and Duffy, 1993), 3 to 5 soil profiles are described for each mappable fan surfaces for a total of 16 profiles. Soil profile descriptions include Munsell Hue, sedimentary structures, root traces, and textures for each soil horizon. The following sedimentological characteristics of deposits exposed at these sites were described where notable: clast sorting, degree of clast support, clast imbrication, normal or inverse graded bedding, clast size, textural variations, and cross-bedding. Soil samples were collected for laboratory analysis at 0.5 to 1 foot intervals from both auger holes and pits depending on the size of the exposure from a combination of sixteen auger holes and backhoe pits.

Metabasalt cobbles derived from the Catoctin Formation were chosen for weathering rind analyses because this resistant bedrock unit is thick and widespread along the Blue Ridge range, and because the cobbles displayed a clear progression of weathering from young to old. Modified procedures by other workers using weathering rinds on mafic rocks were used as a guide for this study area (i.e., Mills and Allison, 1995). Weathering rinds on fine-grained greenstone clasts of fist-to-double-fist size were observed for approximately thirty randomly chosen clasts from the B horizon at 17 sites. As shown in Figure 6, three patterns of weathering rinds were observed for greenstone

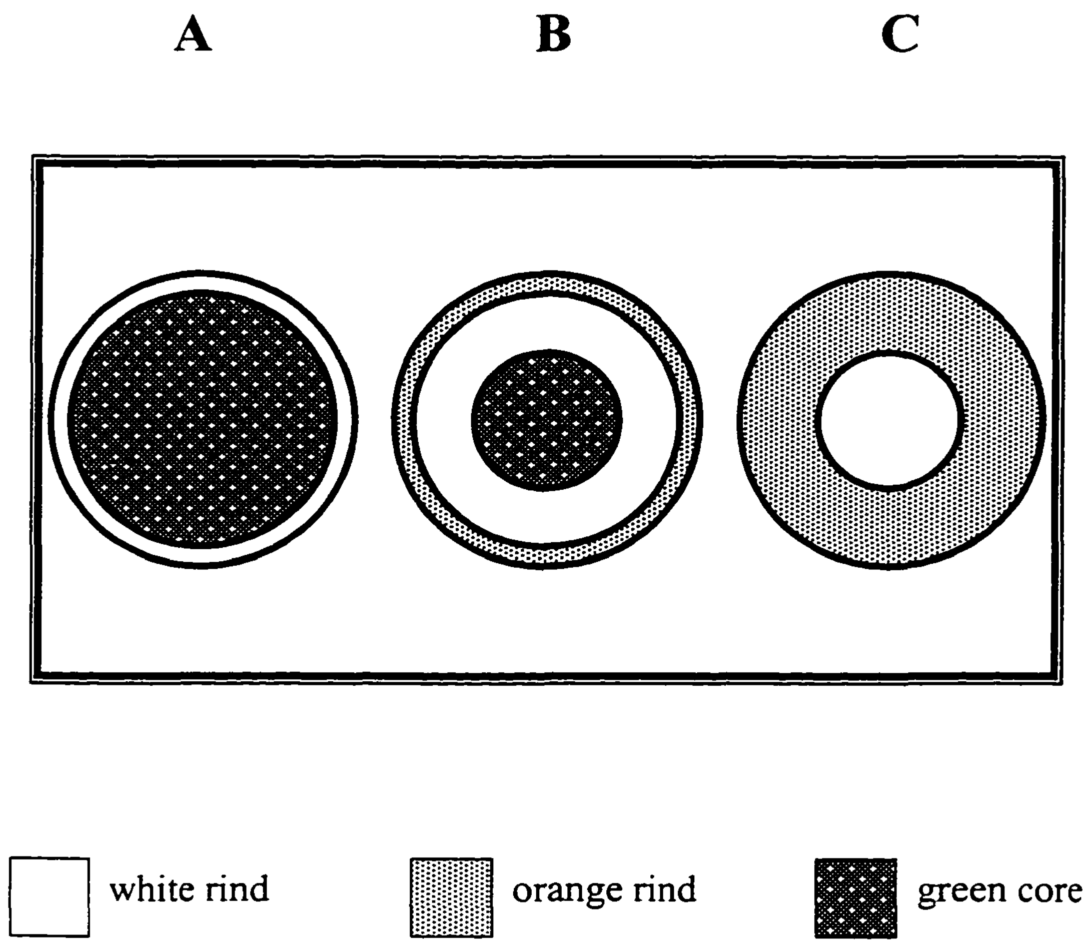


Figure 6. Clast weathering scale, created for greenstone cobbles. A represents the least weathered, most competent rocks, with a small gray rind and dark green core. B is indicative of an intermediate amount of weathering. These rocks have thick orange and gray rinds with or without a dark green interior. C represents well weathered cobbles with a thick orange rind and a gray interior rather than dark green. These cobbles are weathered completely through and are friable.

clasts. An "A" was assigned to competent clasts which displayed little to no pale gray rinds and had dark green-gray interiors when cracked in half with a rock hammer. These clasts were fairly fresh; little to no chemical weathering was apparent. A "B" was assigned to clasts containing a thin orange exterior rind and large gray interior rinds. Most of these clasts displayed a small dark core interior but not all. Lastly, a "C" was assigned to those clasts with a thick orange rind and gray interior. These clasts were not competent, most of the original rock having been subject to significant chemical alteration, and were easily crushed with a rock hammer.

Laboratory Methods

In the laboratory, particle size analysis and total free iron content were determined for each sample. The matrix between large clasts was used during these procedures. A modified hydrometer method (Carter, 1993; Day, 1965; Gee and Bauder, 1979; Foth and others, 1982) determined the percentage of 4 μm clay in the less-than-2mm fraction of the matrix samples (Appendix A). The samples were treated with sodium hexametaphosphate for dispersion then wet sieved to remove the sand fraction. The remaining sample was placed in a standard settling tube and a hydrometer was used to measure the percentages of sand, silt and clay. Total free iron was measured from the B horizon at seventeen sample sites. The Department of Crop and Soil Environmental Sciences at Virginia Polytechnic Institute ran DCB extractable Fe (dithionite-citrate-bicarbonate) analysis on each sample for the percentage of the whole soil (e. g. Jackson et al., 1986). Six samples from DCB-Fe were washed once with 1 M NaCl, followed by two washings with $(NH_4)_2CO_3$ and oven dried at 105 °C. Samples were ground and a 5 mg subsample was used for Kaolinite and Gibbsite Differential Scanning Calorimeter (DSC) Determinations. The DSC determinations were not statistically representative of the whole area due to the small number of samples but did give insight on possible relative ages of the fan deposits. The maximum percentage of clay and total free iron from the B horizon of each sample site were used to provide interpretative data for the determination of relative ages of the alluvial fans.

Statistical Methods

One objective of this project was to see if statistical analyses will distinguish alluvial surfaces based on specific weathering criteria. Hierarchical cluster analyses and canonical discriminant function analyses (Davis, 1986) of the weathering criteria measured were performed using a statistical computer program, SYSTAT. Agglomerative clustering, one type of hierarchical cluster, begins with all objects separate, then successively combines the most similar objects and clusters until all objects are assigned to a single, hierarchical group (Davis, 1986). Hierarchical cluster analysis determines the natural grouping in each data set by utilizing Euclidean distance metrics and complete linkage methods otherwise known as the furthest neighbor. The furthest neighbor method defines the distance between two clusters as the distance between the two furthest points in each cluster (Kovach et al., 1988). All data used standardized values unless common scales were used, (e. g. Munsell hue). Soil and rind weathering variables were calculated separately in order to compare the effectiveness of each criteria. One cluster analysis was used to determine the grouping for the variables Munsell hue, clay percentage, total iron %, and height above the stream for specific sample locations. Another cluster analysis determined grouping for the variables A, B, and C from the weathering rind criteria for similar sample locations.

The canonical discriminant function was used to test each grouping variable decided by the cluster analysis. This analysis was used to test multivariate differences among groups, which variables were most useful for discriminating among groups, if one subset of variables performs equally well as another, and which groups are most alike and most different (Davis, 1986). A combination of calculations using F matrix, F statistics, eigenvalues and canonical correlation, canonical scores for group centroids, and summary of the variable moved at each step in stepwise analyses produced the canonical scores plot for both soil and weathering rind criteria.

Longitudinal Profile

Longitudinal profiles or stream profiles are one way to display the differences in elevation between individual fan sediments and stream elevation with respect to the Blue Ridge Mountains. The longitudinal profile was created using a mixture of established and new techniques. The stream was plotted by using the distance (m) and height (m) of the stream from the mountain front to the distal margins of the fan complex. A transect was plotted from the upper edge of the fan complex along the mountain front at an elevation of 280 meters to the distal edge of the complex at 200 m. Sample sites were projected onto the transects using an arc rather than a straight line because a straight line would project the sample location onto the stream transect at an incorrect elevation

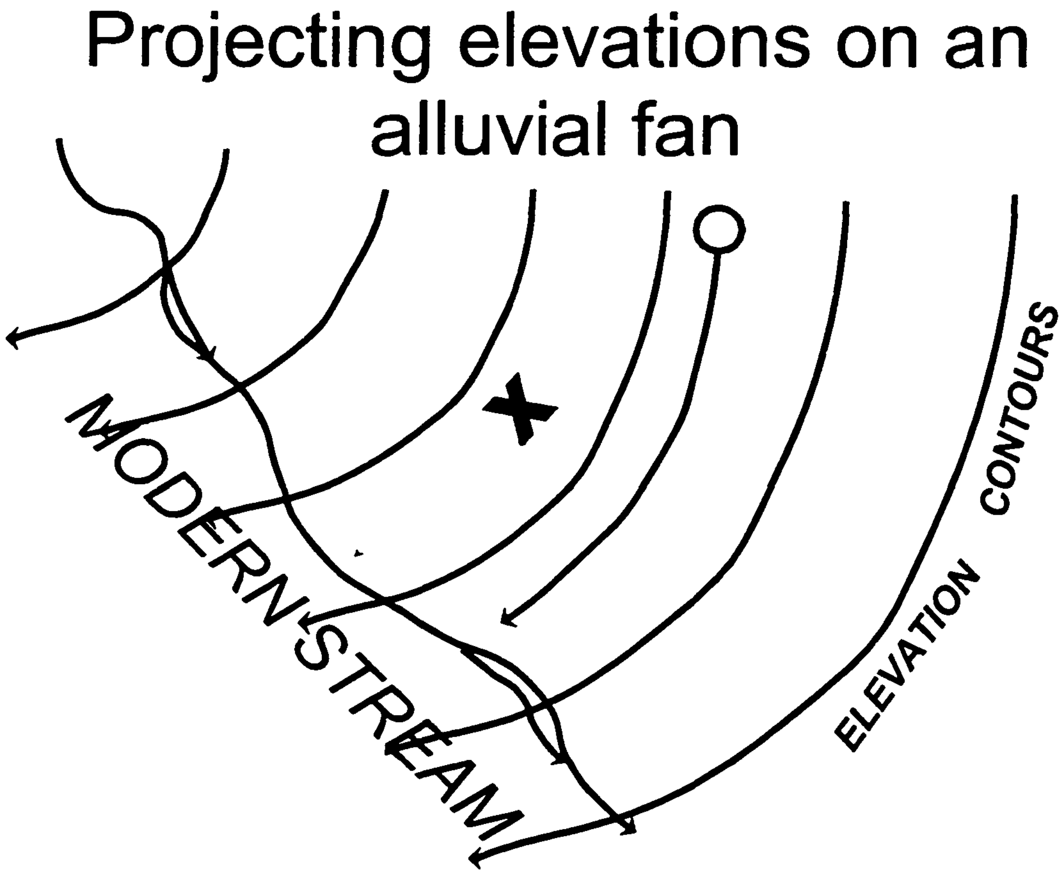


Figure 7. Procedure used to create longitudinal profile. A transect of the fan complex was plotted from the mountain front to the distal edge. Sample sites were projected onto the transect using an arc instead of a straight line in order to establish correct relative elevation.

(Figure 7). The differences in elevation between stream and site location were used as part of the statistical analyses.

CHAPTER III

RESULTS

Map of Alluvial Fan Sediments

Alluvial surfaces in the field area have been highly dissected into many fan remnants. Most of these features are broad sloping surfaces but some are eroded into isolated rounded hills. The geologic map of the field area (1 : 24000) groups alluvial surfaces into fan map units with similar elevations above the stream and degree of dissection by small stream valleys (Figure 8). The adjacent map units are usually separated by distinct geomorphic breaks such as long linear or curved scarps. The four map units recognized are from oldest to youngest-Qf1, Qf2, Qf3, and Qal (floodplain).

The step-like topography, which characteristically describes most fan complexes along the Blue Ridge, was also evident in the study area. All surfaces are laterally extensive and continuous, except the older, more dissected, higher surfaces. The oldest surfaces, Qf1, are high terrace remnants as much as 30 m higher than the floodplain found at locations far from the stream. Several of these rounded hills lie far from the mountain front, surrounded by younger, lower surfaces. Intermediate alluvial surfaces, Qf2, form extensive planar-to-convex terraces 5-15 m higher than the floodplain that are partially consumed by incising valleys. Younger, more recent surfaces, Qf3, are low terraces 1-3 m higher than the floodplain that occupies a narrow belt at elevations closest to the stream and mountain front. The floodplain of Stony Creek (Qal) lies in a narrow valley entrenched into the lowest terrace surface.

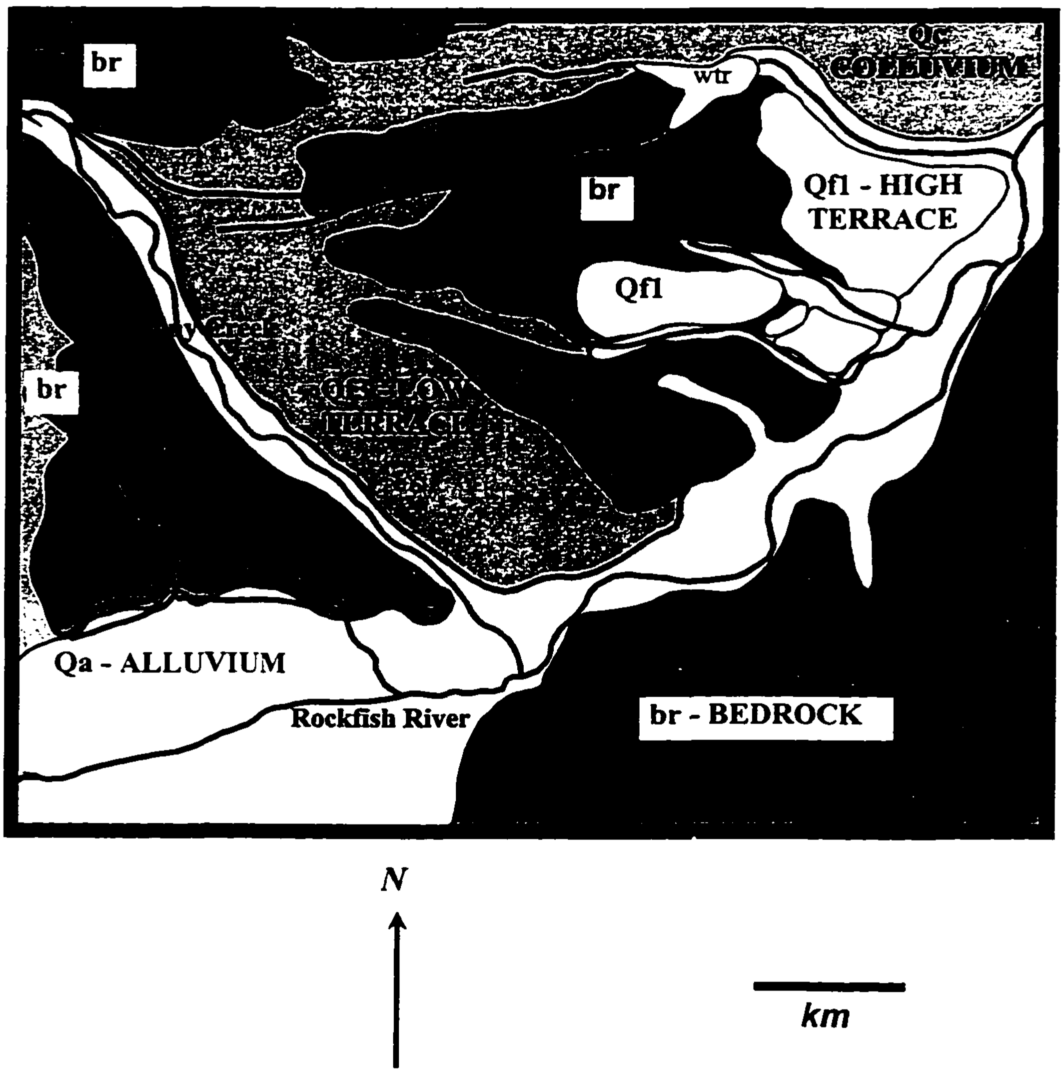
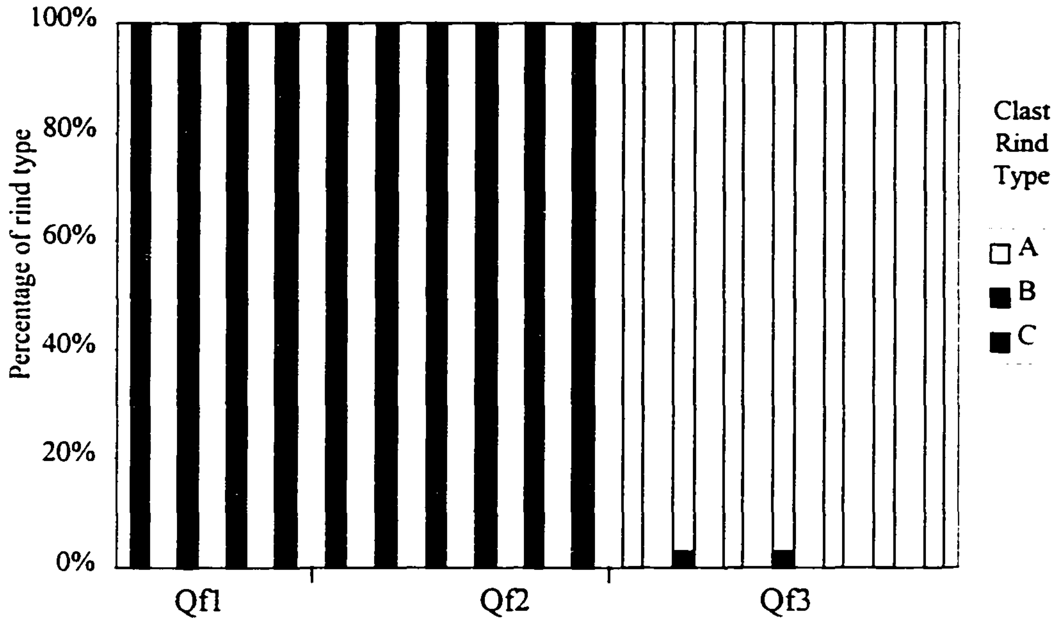
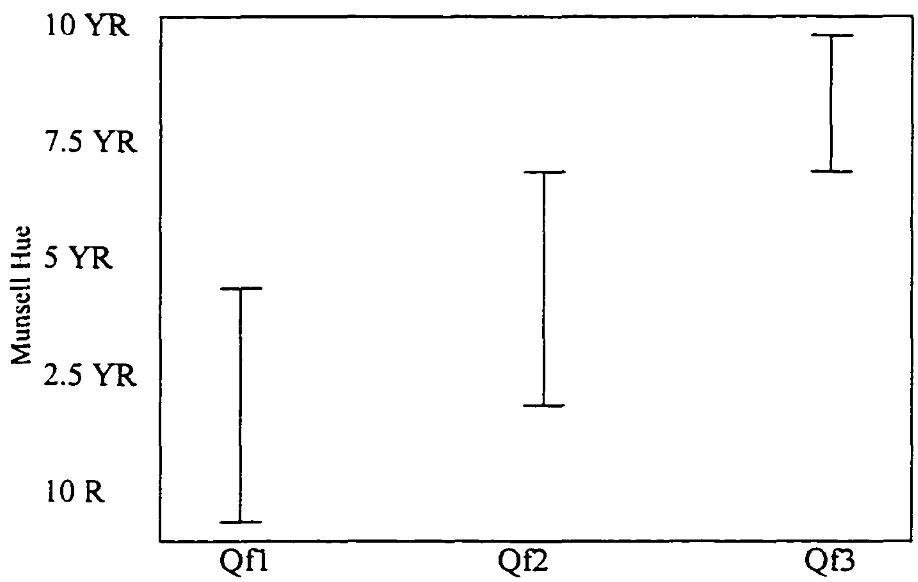


Figure 8. Geologic map of alluvial fan surfaces in Nelson County, Virginia. The oldest fan surfaces (Qfl) are highly dissected and weathered and contain incompetent cobbles. Intermediate-age fan surfaces (Qf2) are somewhat dissected with moderately weathered soils and cobbles. The youngest relict surface (Qf3) are slightly dissected and weathered with weakly weathered cobbles. The floodplain deposit (Qal) is not dissected and contains fresh, coarse alluvium.



Clast Weathering Rind Data



Colors from Maximum Bt

Figure 9. Soil color and weathering rind data charts. These data shows distinct progressions between alluvial surfaces.

Soil color and clast weathering data show distinct progressions between the three alluvial terraces (Figure 9). All Qf1 surfaces have red-orange (5YR to 10YR) soils and only contain B and C clasts. The weathering rind patterns display complete saprolization of the stones indicating these greenstones have been subjected to weathering for extended lengths of time. Qf2 surfaces have a combination of all three rind types and very few thoroughly rotted clasts; soil colors range from orange-to-reddish (7.5YR to 2.5 YR). Qf3 surfaces contain thin, pale A rinds and yellow-to-brown soils (10YR to 7.5 YR), indicating relatively young surfaces.

Topographic Position of Alluvial Surfaces

Sixteen sites with auger holes, soil pits or exposures (Figure 1) were used to evaluate the sedimentology, stratigraphy and soil development on the mapped fan surfaces (Figure 8). The stream and terrace profiles in Figure 10 represents Stony Creek and the 16 site locations used for detailed sampling. The relative age identified for the deposits at each site is based on topographic differences in elevation. All of the sample sites fall at or below the elevations of the mapped terrace surfaces when projected to the stream as described above. Those sites lying notably lower than expected for the correlated (i.e., Qf1) surface shows signs of surface erosion and truncated soil profiles.

Sedimentology of Alluvial Deposits

The oldest alluvial surfaces, Qf1, (Figure 11) are located at higher elevations in the field area and at distal margins of the fan complex. An example of an exposure in a

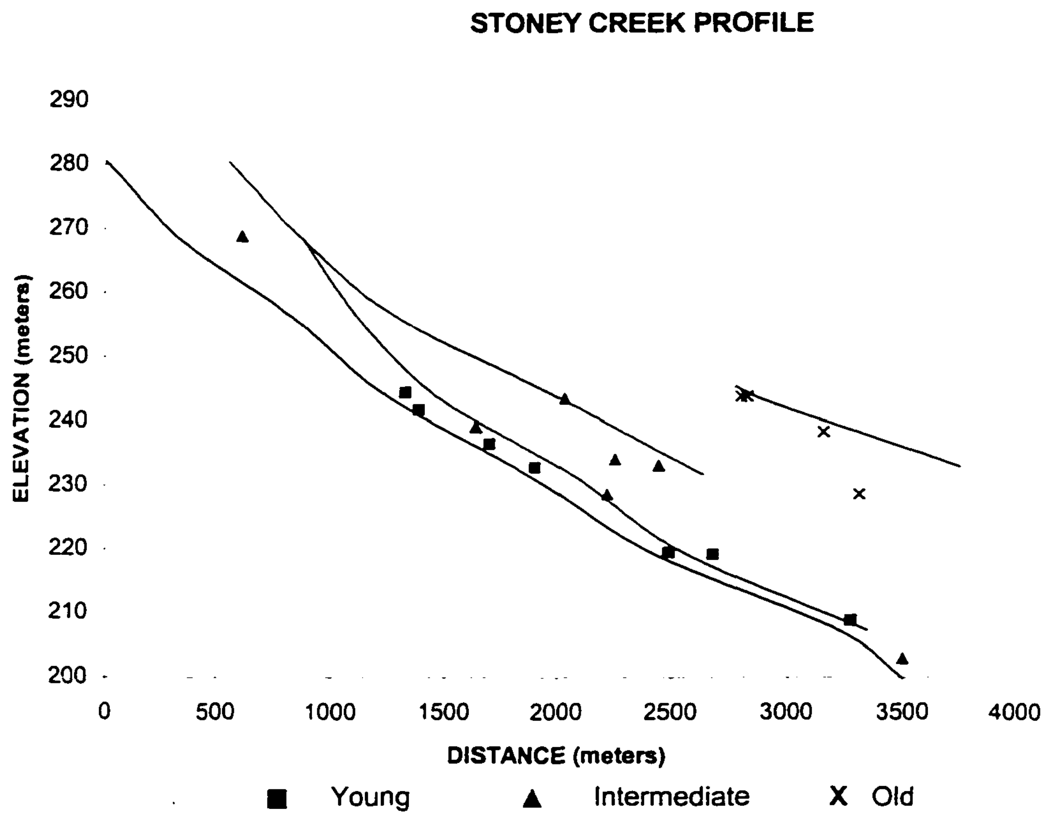


Figure 10. Stony Creek longitudinal profile. Stream and terrace profiles represent Stony Creek and four alluvial surfaces (Qf1, Qf2, Qf3, and Qal). Sample sites were projected onto transects using an arc (see Figure 8) because a straight line would project the sample location at an incorrect elevation. All sample sites fall on or below the mapped terrace surfaces. Those sites which plotted lower than expected displayed signs of surface erosion.

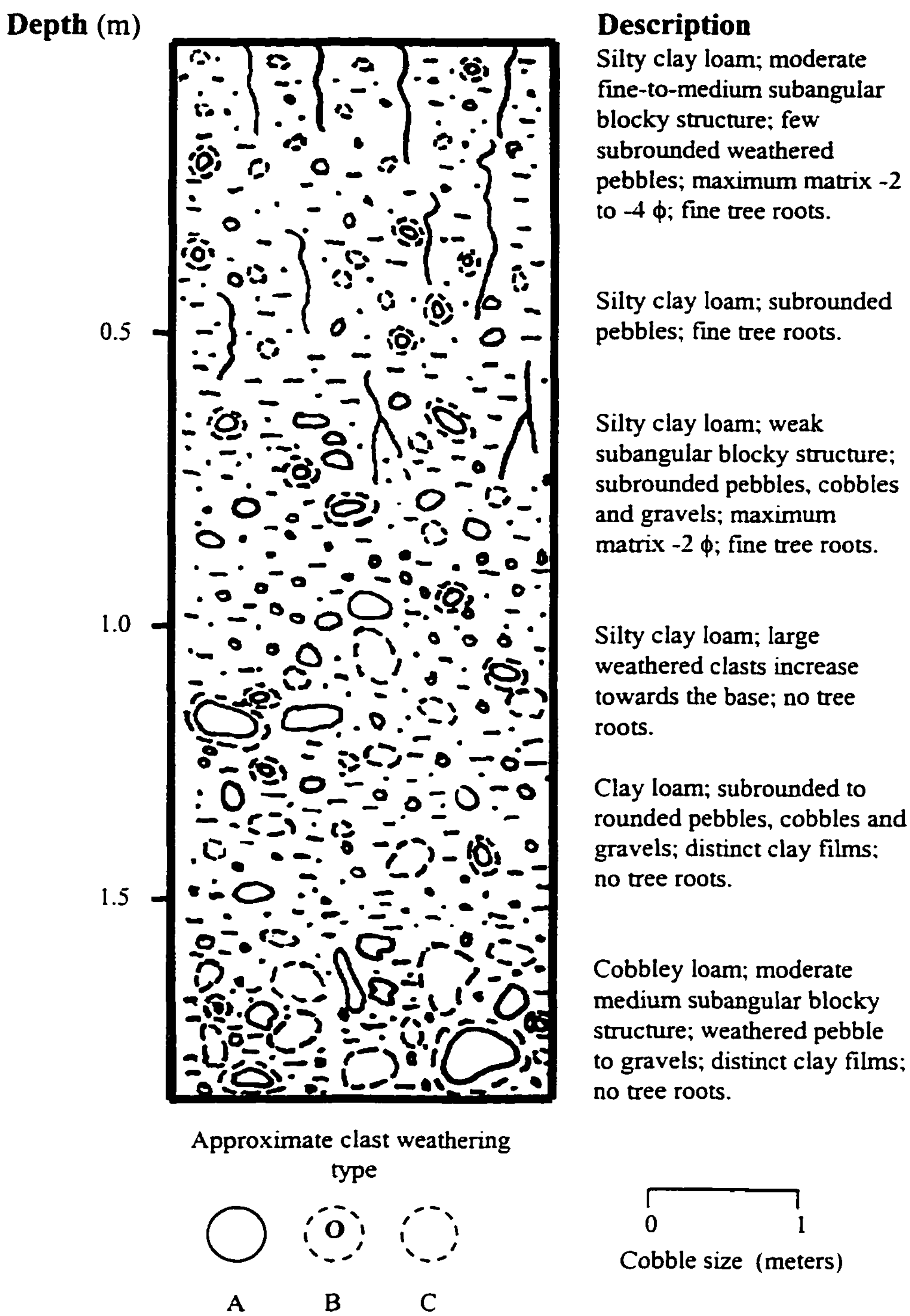


Figure 11. Sedimentological characteristics of Qfl Deposit (site Cp4). The sample site, Cp4, represents a Qfl exposure located along the western margin of the field area (see Figure 1).

Qf1 surface is backhoe pit Cp4, located at the most eastern side of the field area, and 1.8 m deep from the top of the surface. Sand beds or lenses mixed with clay were apparent in the upper meter of the section. These lenses consist of sand layers almost weathered completely to clay. Sedimentary structures were scarce except for normal grading upward sequences. The cobbles and gravels increase in size and weathering rind patterns from one meter to one half meter. The coarsest gravels were located at lower elevations in the deposit. Clay films become distinct in the lower section, where cobbles are weathered completely to clay.

Pebble size sediments at one meter in depth within silt and clay represent overbank deposits and overlie channel deposits of larger more weathered cobble size material. The sand deposits recognized in the upper half of the deposit could be ghost clasts that were once deposited in upper flow regime conditions (Darby, 1990) or by debris flow. Cobble imbrication and cobble-to-cobble contacts were observed towards the bottom of the section and inferred flow direction is generally to the southeast.

Intermediate-age, Qf2, terrace surfaces are found at middle elevations and flank the sides of older, Qf1, surfaces (Figure 12). Backhoe pit FD4 was located to the northeast of Stony Creek towards the middle of the fan complex and was 1.5 m deep from the top of the surface. The stratigraphy of the Qf2 deposit indicates a gradation in the down-section direction from small pebble size material to more gravel size weathered material. These deposits were structureless and range from pebble-to-cobble size greenstone and charnokite clasts within a fine matrix of silt and clay. Cobble size decreases from Qf1 to Qf2 with noticeable inverse grading at the top of the section rather than normal graded bedding.

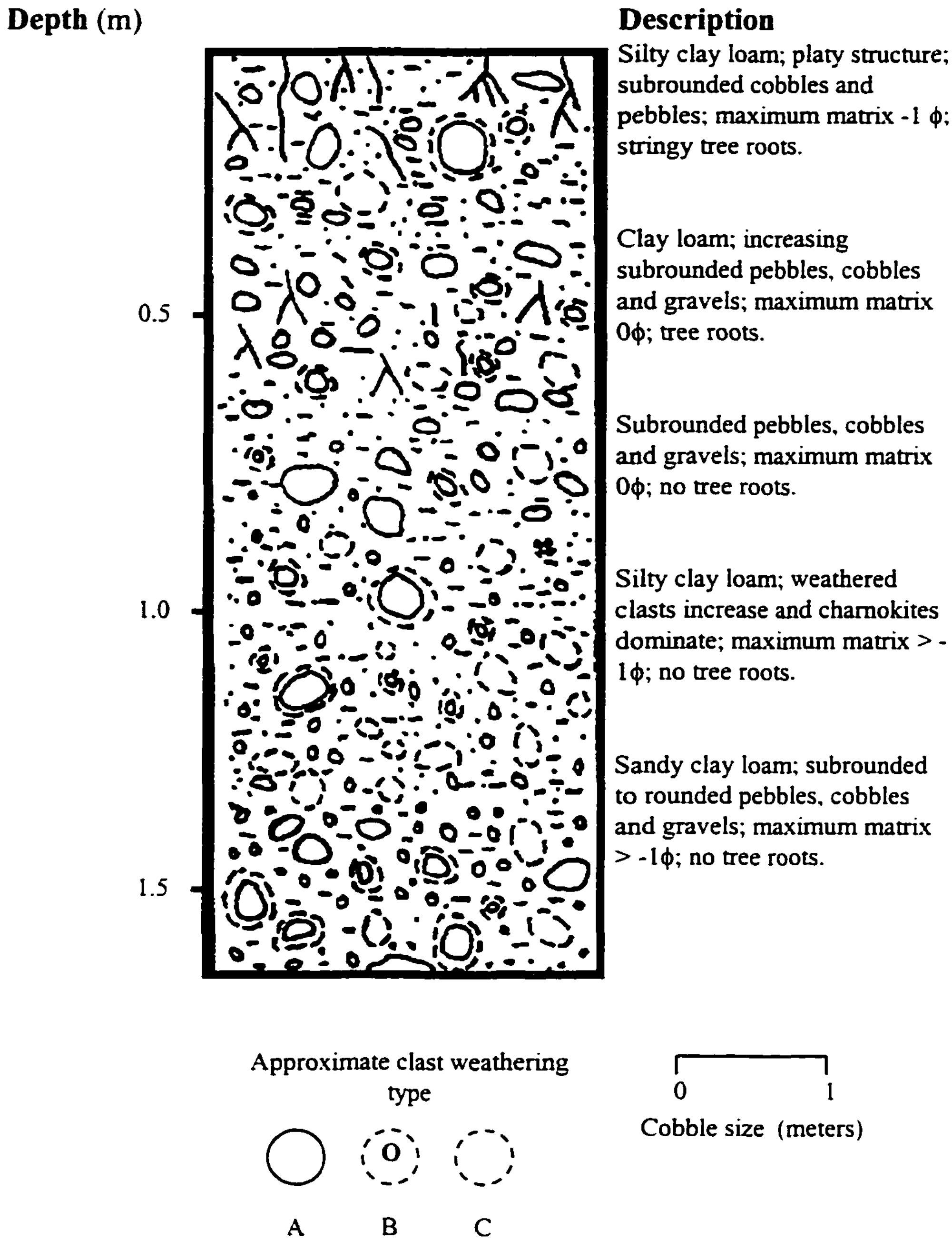


Figure 12. Sedimentological characteristics of Qf2 Deposit (site FD4). The sample site FD4 is located in the northeast section of the field area (see Figure 1) and represents an exposure of intermediate-age deposits.

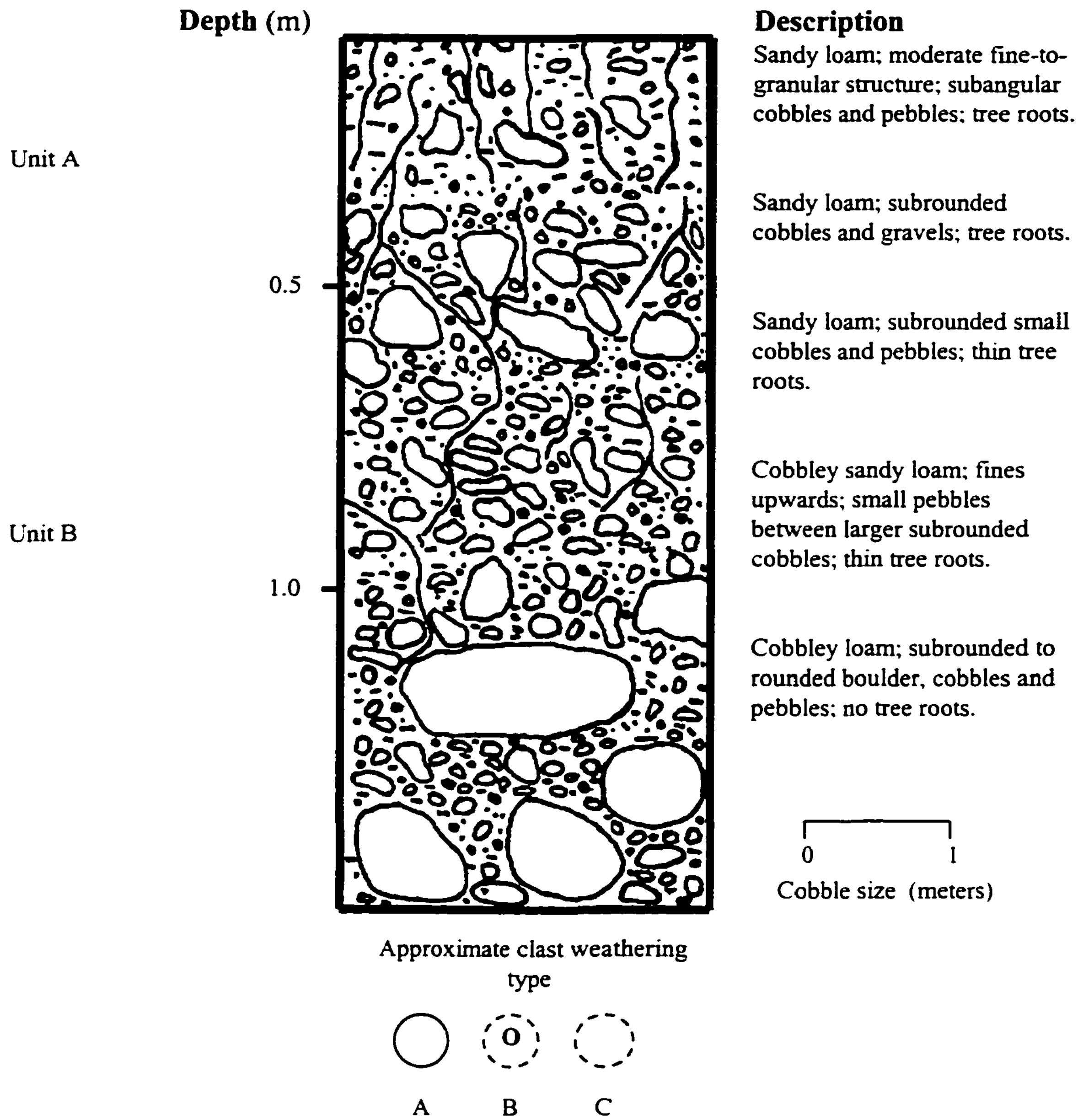


Figure 13. Sedimentological characteristics of Deposit Qf3 (site Mid1). The sample site Mid1 represents a deposit from a young relict fan surface. This site was sampled from an exposure found at the distal margin of the fan complex (see Figure 1).

The deposit at site FD4 (Qf2) is interpreted as a possible debris-flow or a possible hyperconcentrated-flow consisting of several channel and scour bars based upon the large floating clasts, the disorganized clast fabric, and slight imbrication. Matrix-supported coarse clasts in massive beds with extremely poor sorting and reverse grading resemble sediments characteristic of debris flow deposits (Costa, 1988).

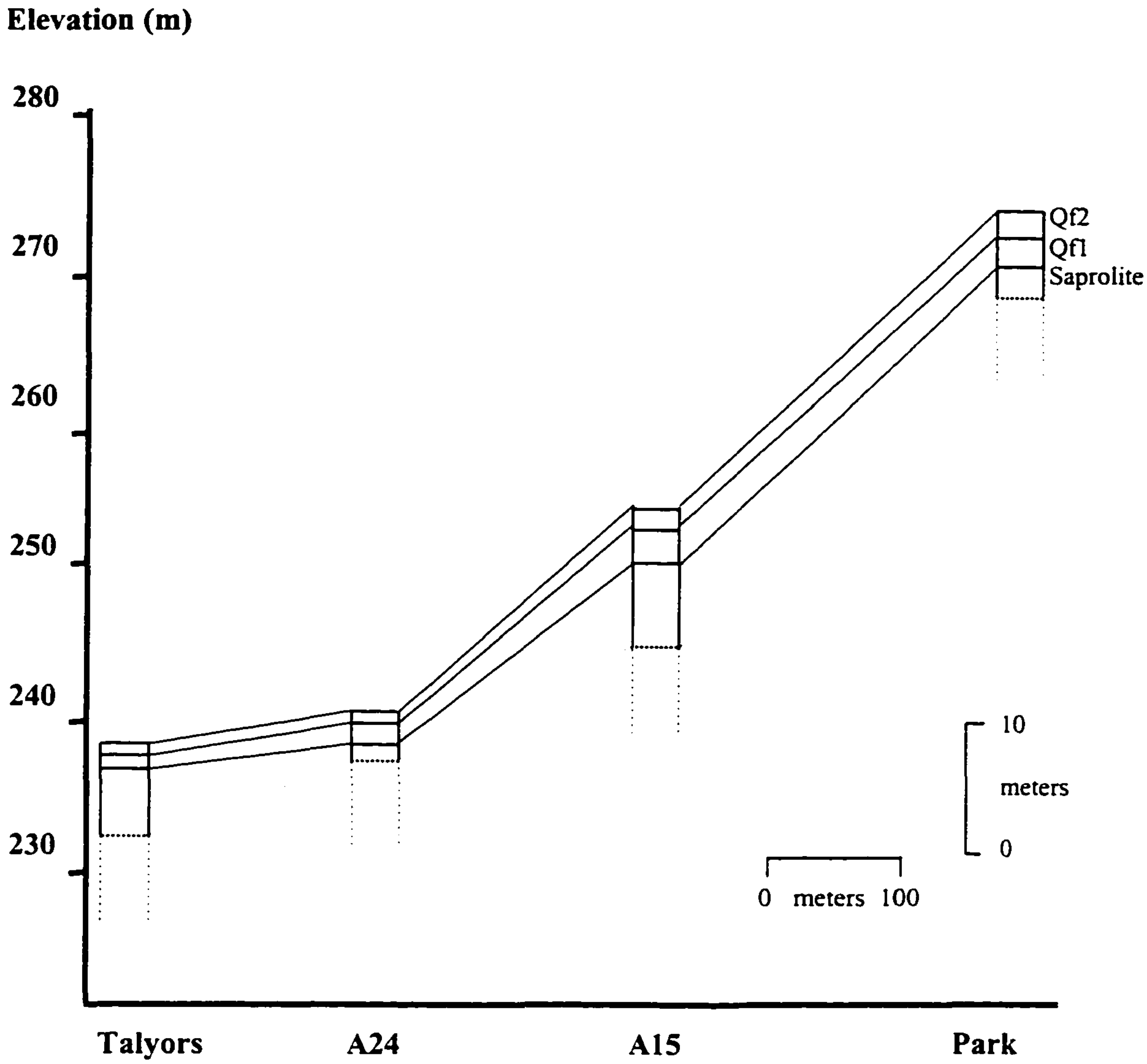
Relatively young alluvial surfaces, Qf3, interfinger with Qf2 surfaces and parallel modern drainage ways. The exposure Mid1 was located along the eastern margin of the creek at the distal edge of the fan complex (Figure 13). The exposure was 1.5 m in depth from the top of the surface. Clast-supported cobbles were sub-angular and the overall coarseness of the deposit increased in the down fan direction. Cobbles-to-boulder size gravels fine upward and imbrication in the upper level of the deposit indicates mode of deposition was to the southeast.

The lower elevation unit, Qf3, contains small sub-angular clasts with an increase in sand in the matrix and is deposited only along the eastern margin of Stony Creek. The sedimentary facies in the Qf3 deposits resemble deposition caused by fluvial activity from Stony Creek but lack typical sedimentary structures such as stratification (Costa, 1988). However, strong imbrication and channel bar deposits indicate turbulent flow regimes characteristic of stream flow deposition. The thickness of the Qf3 deposit is unknown.

The floodplain deposits, Qal, are located close to Stony Creek and surround the steep distal edges of other alluvial surfaces. These deposits have been created by recent fluvial activity and contain clast-supported sediments. The floodplain surface is the lowest surface found in the field area.

Along the western margin of Stony Creek, Qf1 and Qf2 units overlie saprolite or weathered bedrock in a series of massive or elevated outcrops (Figure 14). The units are extensive, continuous, and the thickness of the individual units decrease in the down fan direction. The units are moderately-to-poorly sorted with a pronounced break in weathering marking a hiatus between the two deposits. The contrast between weathered cobbles and the differences in clay textures defines the break between surfaces (Appendix E). Metabasalts and charnokites dominate the gravels and cobbles within the units ranging in average size from 1 cm to 30 cm with largest clasts up to 1.5 m at the base of the mountain. The 1.5 m clasts are mostly in the lower half of the units. Grain size of the cobbles and gravels decrease in the down fan direction.

Thus fan deposits in Nelson County characteristically contain pebble-to-boulder size gravels in matrix-supported units beneath older surfaces (Qf1 and Qf2) and clast-supported units beneath younger surfaces (Qf3 and Qal). These differences suggest the older two surfaces formed primarily by debris flow and the younger surfaces, by fluvial storm flows.



Grain Size Chart Maximum Clast Size (ϕ)
Site Locations

	Taylors	A24	A15	Park
Qfl	>-6	-7.5	-9	-10
Qf2	>-6	-8	-8	>-10

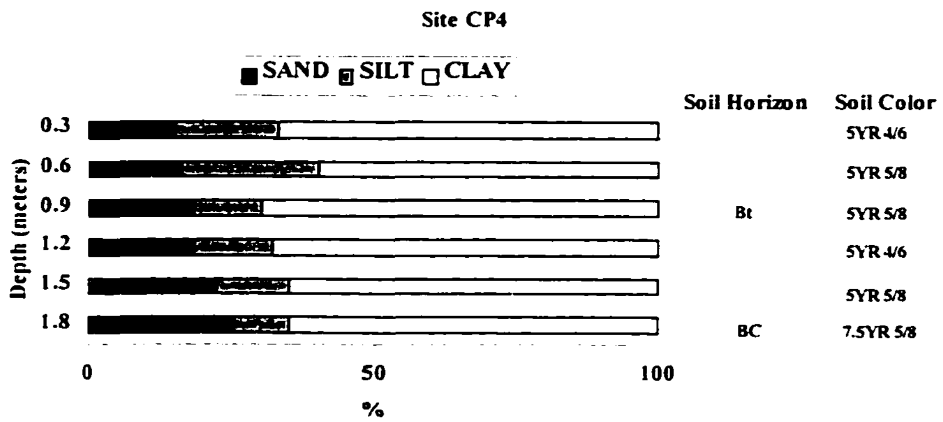
Figure 14. Qfl and Qf2 alluvial surfaces as seen in cross-section along the western margin of Stony Creek. Qfl and Qf2 deposits overlie saprolite found along the western margin of Stony Creek. Extensive amounts of stream incision has eroded and exposed the extensive and continuous deposits. Grain size decreases towards the distal margins of the fan complex.

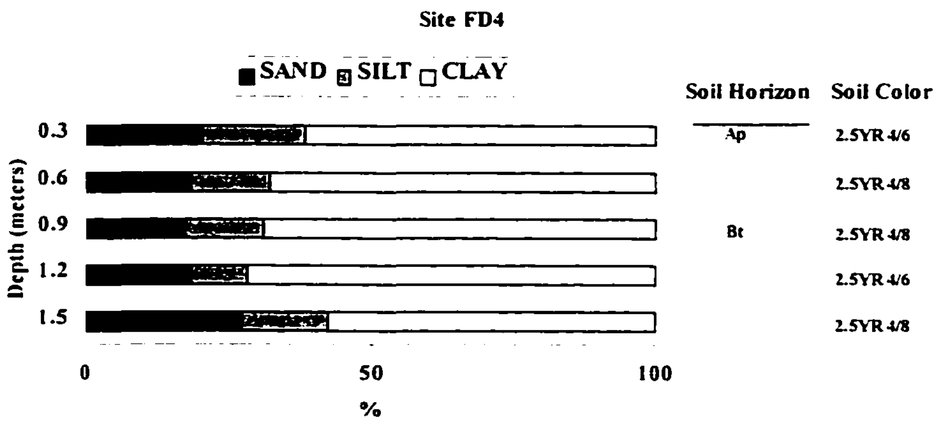
Soil Profile Characteristics

The textures of horizons in the soil profiles found in the field area are inherited from heterogeneities in the parent material and modifies by argillic horizon development. The argillic (Bt) horizon for modern soils forms by illuvial accumulation of pedogenic materials such as clay and sesquioxides, and defined by color, blocky fabric, and clay skins on ped faces (Mack and James, 1992). In the present field area these criteria are difficult to apply to older surfaces because many of the horizons have been stripped by erosion off of the top of soil profiles. In the Coastal Plain, which is dominated by quartz-rich sediments, parent materials weather to clay slowly and Bt horizons can form only over long periods of time. The soils found in the field area are derived from relatively mafic, stratified parent materials that rapidly generate large amounts of clay and sesquioxides. Layers in stratified alluvium often have different textures and mineral content. Thus the combined pedogenic illuviation and weathering of the parent material can result in irregular increases of clay with depth in the Bt horizon.

Soil development criteria for the three alluvial surfaces (Qf1, Qf2, Qf3) were based on color, maximum Bt clay, total free iron and kaolinite and gibbsite contents. Data in Figure 15 come from analyses of soil profiles in backhoe pits that are representative of all profiles analyzed from each alluvial surface (Appendixes B, C, and D). Floodplain deposits, Qal, were similar to Qf3 deposits and are included in their description.

The Qf1 deposits exhibited Munsell hue colors 5 YR to 10 R and had an average clay maximum percentage of 70 %. In Figure 15 , site CP4 falls within the range of the





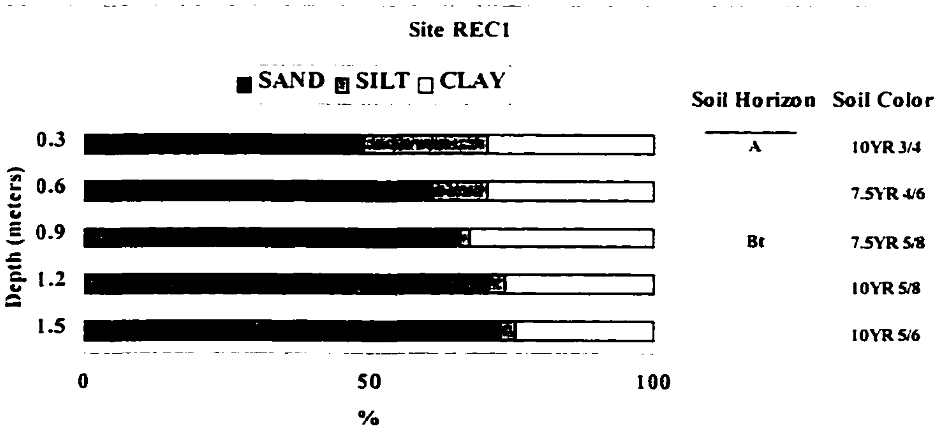


Figure 15. Soil profile data from pits or exposures in Qf1 deposit (site Cp4), Qf2 deposit (site FD4), and Qf3 deposit (site Mid1).

oldest deposit (see Appendix D). Dithionite-citrate-bicarbonate (DCB) extractable iron concentrations were 4-to-5 %, typically; at site CP4 28 % of the sediment was kaolinite and 1 %, gibbsite. The matrix soils in the Qf1 surface exhibited fine to medium subangular blocky structure probably from shrinking and swelling or bioturbation (Mack and James, 1992). Few roots were recognized and no apparent organic horizons were present.

In Figure 15, site FD4 falls within the range of the intermediate deposit, Qf2 (see Appendix D). The Qf2 deposits exhibit Munsell hue colors ranging from yellow-to-red (7.5 YR to 2.5 YR) and had an average maximum clay content of 65% (Figure 15). At most sites concentrations of DCB extractable iron were 4-to-5 % of the whole soil. At site FD4 sediments were 29 % kaolinite and 1 % gibbsite. The soil profile was well developed with an Ap horizon and the deposit thickness of 1.5 m.

The Qal and Qf3 deposits exhibit well developed soil horizons with Munsell hue colors, yellow-to-brown, ranging from 10 YR to 7.5 YR with an average of 10-to-30 % clay (Figure 15). These surfaces have an average of 3 % DCB extractable iron from the whole soil. Kaolinite and gibbsite contents at site Rec1 (16 % and 0.4 % , respectively), were much less than for the other deposits. Many roots were recognized in the section as deep as one meter. The soil texture was rather weak granular in fabric but not very apparent.

Statistical Results

Cluster analysis for soil weathering criteria clustered the data into three groups (Figure 16). With the exception of sample site Cp3, these groups correspond to the terrace surfaces. The sites with yellow-brown hues, low clay and iron percentages, and minimal height above the stream are located at the top of the dendogram. The sites with red hues, high clay and iron percentages, and maximum heights above Stony Creek are on lower end of the dendogram. Site Cp3 has 60% clay which is more similar to Qf2 than Qf1 surfaces, although Cp3 is a topographic high (Qf1). Groups Qf1 and Qf2 clustered together first before joining Qf3 and thereby have more similar criteria or characteristics.

The cluster analysis for the weathering rind criteria grouped all but one site, Cp4, into the same three groups (Figure 17). The top of the dendogram represents those rinds found in topographically lower surfaces. These Catoctin greenstones are competent and have weathering rinds classified as A. The lower edge of the dendogram represents topographically high surfaces with rinds classified as B and C. Sample site Cp4 contains a very small percentage of C rinds (Appendix D) and clustered into the middle group for this reason.

Soil and weathering rind cluster analyses grouped three alluvial surfaces. The groups assigned by the cluster analysis were tested by discriminant function analysis using the same soil and weathering rind data. The discriminant function analysis of soil weathering criteria classified all sample sites into groups except for one, Cp3 (Figure 18). Color was the least discriminating criteria between alluvial surfaces where height above the stream was the greatest discriminator. Factor 1, x coordinate, represents the height above the stream and Factor 2, y coordinate, represents the next best combination of variables (i.e. clay percentages) for each sample location. Factor 1 accounted for 71% of the dispersion between alluvial surfaces. The discriminant function analysis correctly

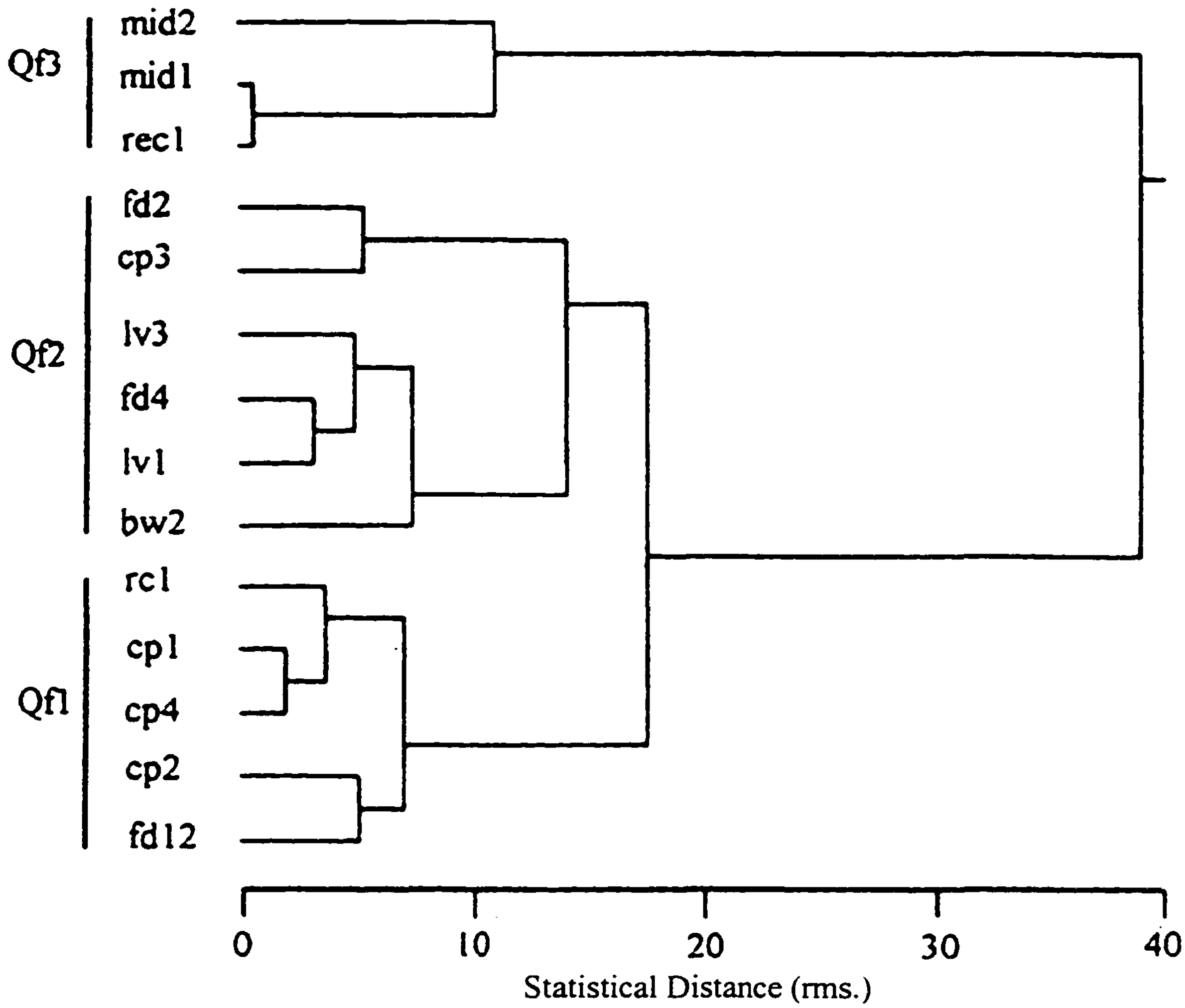


Figure 16. Cluster analysis of soil weathering criteria. Soil weathering criteria includes height above the stream, clay %, total free iron, and color from the argillic soil horizon. Dendogram of soil weathering criteria created by the hierarchical cluster analysis. The least weathered alluvial surfaces, Qf3, are found at the top of the dendogram followed by Qf2 and Qf1. The cluster analysis first grouped Qf1 and Qf2 samples then Qf3. Distance was calculated using the furthest neighbor method for best results (Davis, 1986).

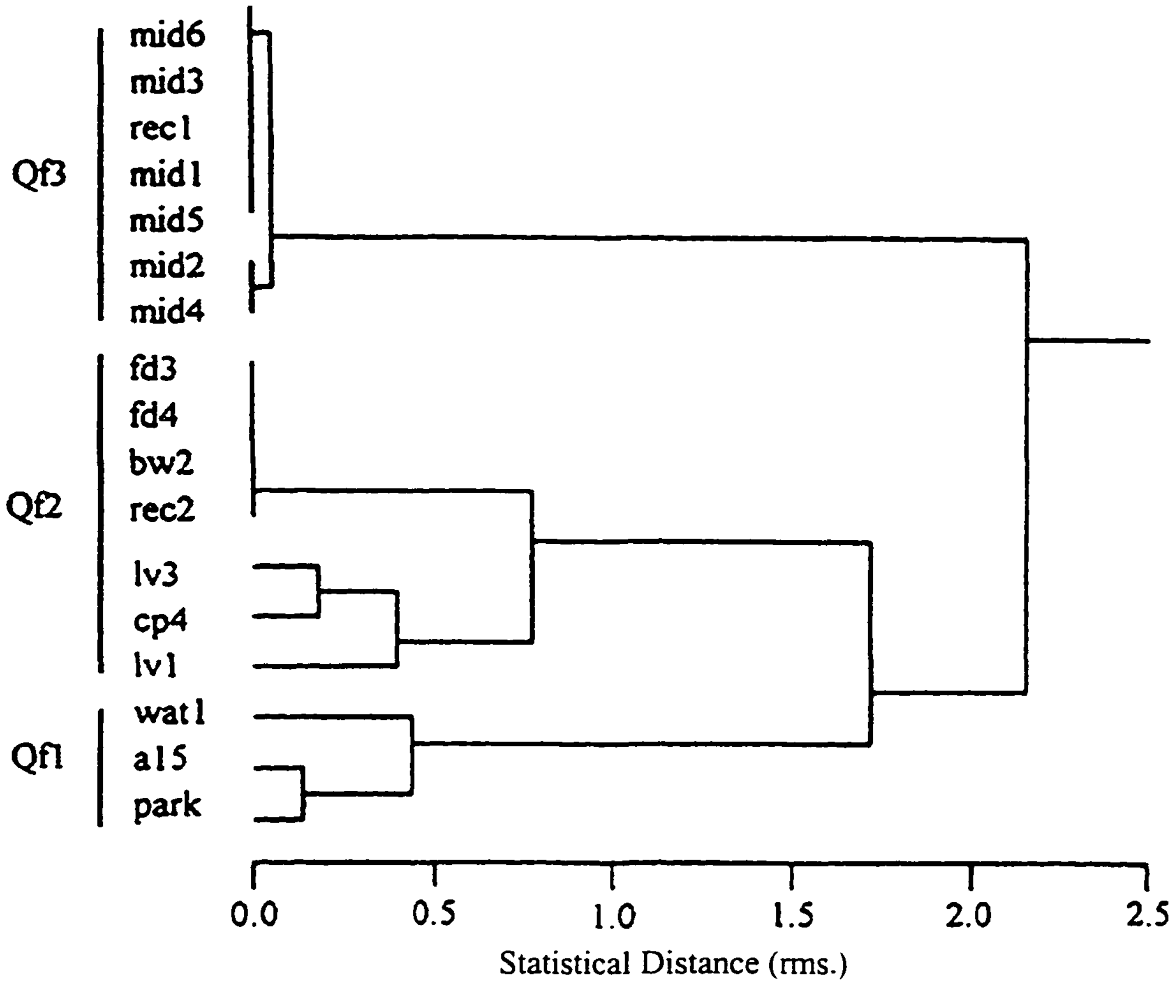


Figure 17. Cluster analysis of weathering rind criteria. The dendogram of weathering rind criteria was created by the hierarchical cluster analysis. The data used in the analysis represents the percentage of each rind type (A, B, C) per sample site on each alluvial surface. The least weathered alluvial surfaces, Qf3, are found at the top, followed by Qf2 and Qf1, which are the most weathered surfaces. Distance was calculated using the furthest neighbor method for best results (Davis, 1986).

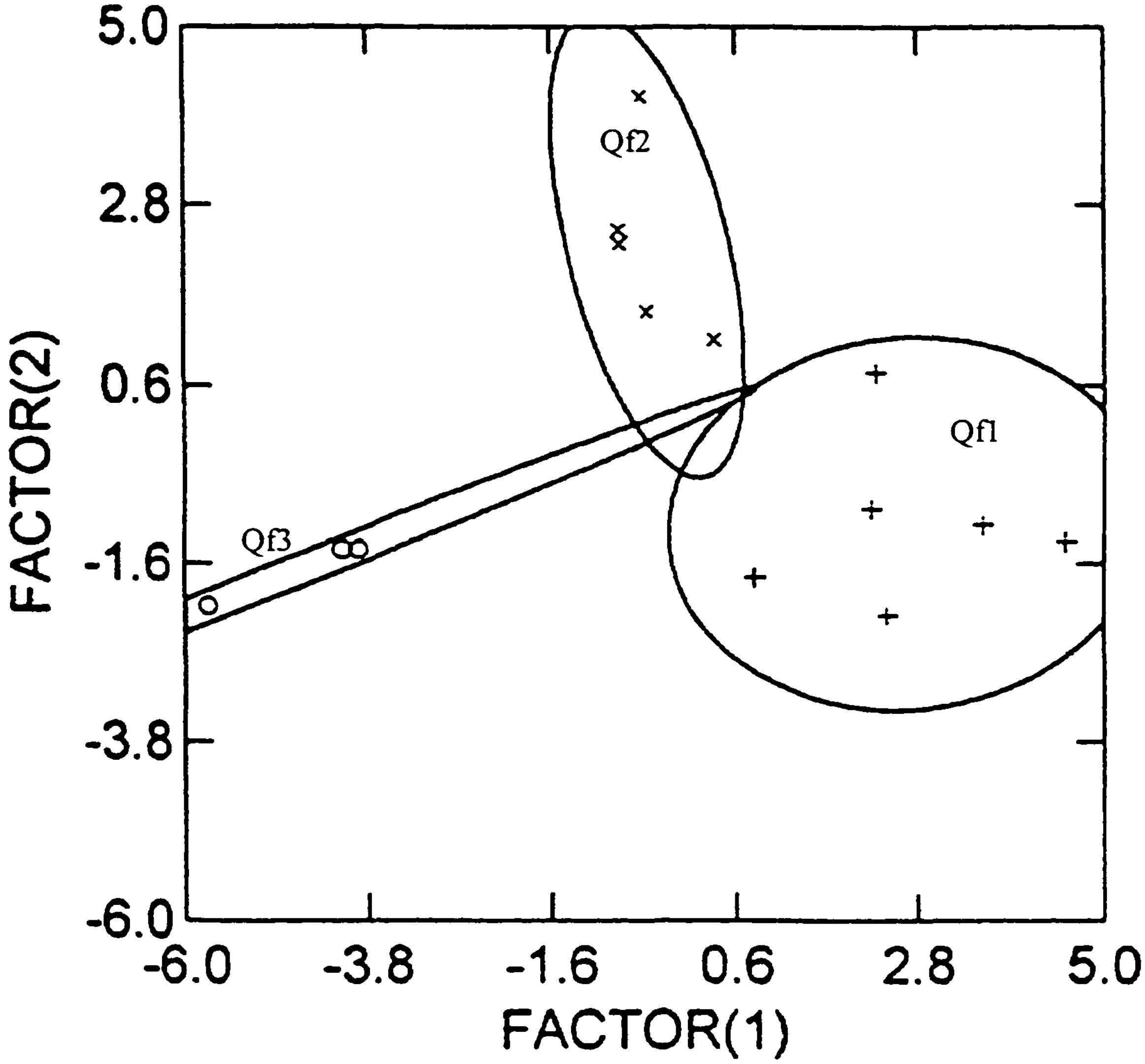


Figure 18. Canonical discriminant function results for soil weathering criteria. Factor 1 represents the greatest discriminator, height above the stream. Factor 2 represents the next best combination of variables (i. e. clay percentages).

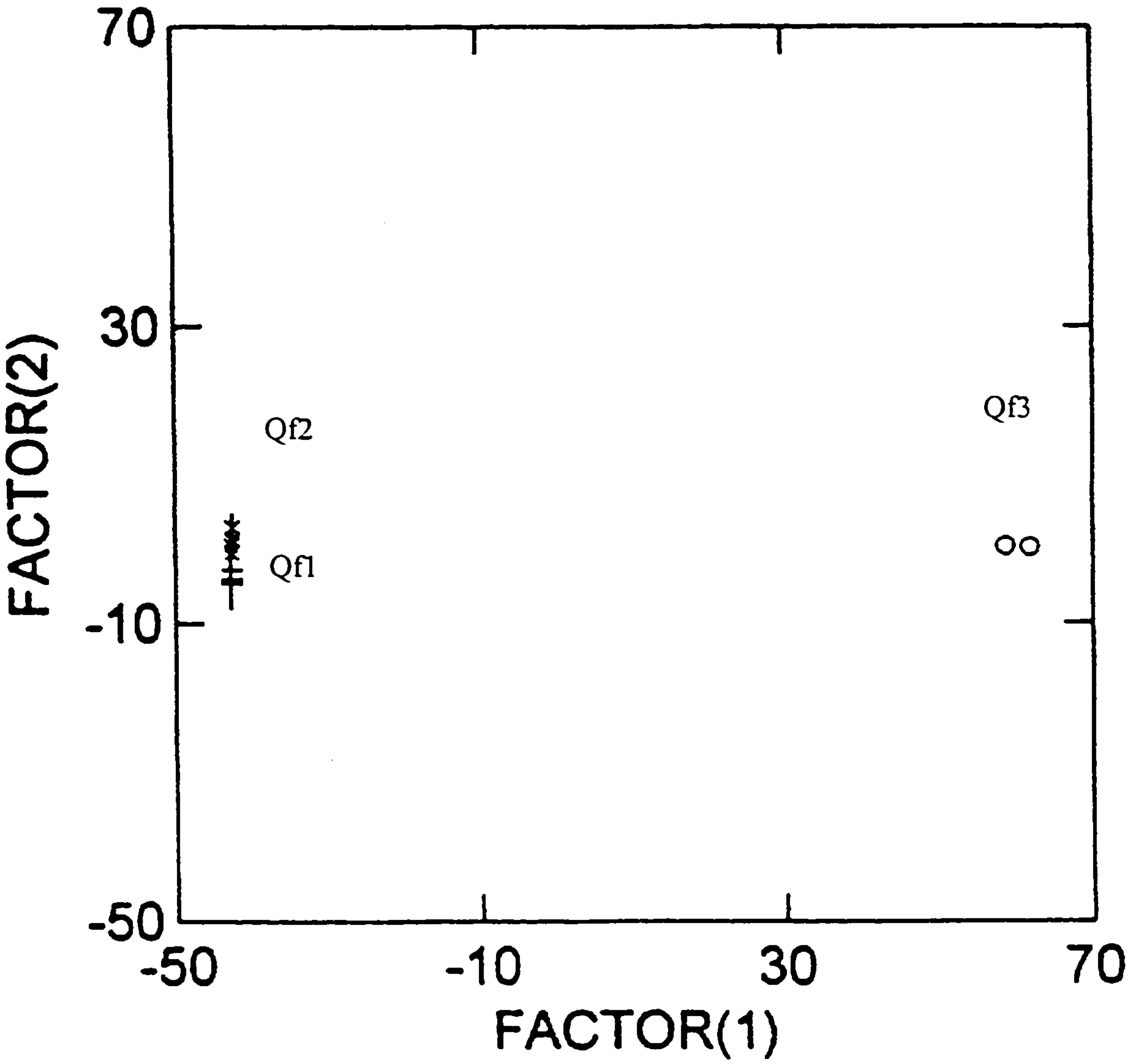


Figure 19. Canonical discriminant function results for weathering rind criteria. The analysis classified all the data the same as the cluster analysis (1 = Qf3; 2 = Qf2; 3 = Qfl). Rind type A was the best discriminator (Factor 1) and rind type B was the least discriminator. Factor 2 represents the best combination of variables.

classified 93% of the data the same as the cluster analysis. Qf2 and Qf1 have similar group means and Qf3 and Qf1 have the least similar group means based on the data, indicating the degree of similarities and differences between the three groups which is similar to what was found in the cluster analyses and the field observations.

The canonical scores plot for weathering rind data shows a similar pattern to the soil weathering criteria and 100% of the data were correctly categorized (Figure 19). B was the least discriminating variable and A (Factor 1) was the greatest discriminating variable. Factor 1 accounted for 99% of the dispersion between alluvial surfaces. Qf2 and Qf1 plot close together and Qf3 plots at a distance.

Three alluvial surfaces Qf3, Qf2, and Qf1 were grouped using cluster analyses and tested by canonical discriminant function. In the future, if larger exposures were available so that samples from B and C horizons could be collected and horizon thickness measured, analysis of the "clay accumulation index" = $\sum [(B_c - C_c \times (T)]$, could be calculated and possibly better differentiate surfaces. B_c is the percent clay in the argillic horizon, C_c is the percent in the C horizon, and T is the thickness of the argillic horizon. Levine and Ciolkosz (1983) utilized this "clay accumulation index" for modeling ages for the beginning of soil development in Altonian and pre-Wisconsinan soils.

CHAPTER IV

INTERPRETATION AND DISCUSSION

The information collected during this investigation indicates there are four alluvial surfaces (Qf1, Qf2, Qf3, and Qal) which were deposited during several different time periods. These surfaces are distinguishable and mappable based on soil and weathering rind criteria, topography, and stratigraphic relationships. This chapter analyzes the information generated in order to reconstruct the geomorphological history of the area.

M. J. Bartholomew (1977) first studied the geology of the area and recognized two Quaternary units. As mentioned previously, these units were alluvium and terrace deposits. Bartholomew described the well-dissected bajada as a confluence of alluvial fans with floodplain deposits and mountain stream deposits. He describes the small creeks in the area such as Allen Creek as abandoned channels cut into the bajada by Stony and Little Stony creeks when they formerly drained eastward. My mapping and statistical analysis indicates three relict alluvial surfaces rather than two surfaces. These surfaces formed during different periods of time and are marked by progressively greater weathering of the fan deposits. The Qal unit of Bartholomew (1977) is now mapped as Qf3 and Qal; Bartholomew's Qtd unit is now mapped as Qf1 and Qf2.

Mapping of the different alluvial surfaces concurs with statistical data which indicates these surfaces were deposited during episodes widely spaced in time. Work by Duffy (1991) described similar patterns of fan surfaces on the opposite side of the Blue Ridge that were primarily created by fluvial processes (Figure 5). Older fan remnants were distinguished from younger deposits based on the extreme weathering of soil and gravels and the great thickness and lateral extent of the deposits. The event that caused F1 deposits was suggested to be larger in degree or longer in duration than the events that produced the younger deposits. The intermediate (F2) and young (F3) gravels filled the valleys carved into the F1 deposits and possibly formed during a series of relatively short-lived episodes (Whittecar and Duffy, in press). Small streams have dissected all deposits but the severity of stream dissection increases with age.

Similar characteristics are recognized in Nelson County fans (Figure 8). As in Augusta County, the oldest surfaces (Qf1) are found furthest from the mountain front and only the younger surfaces (Qf2 and Qf3) are found close to the mountain front. In both areas, the oldest fan deposits contain highly saprolitized clasts and progressively younger deposits hold increasingly more competent clasts.

Thus the processes and timing that created the fan complexes in Augusta County and Nelson County appear similar in many ways and may reflect the same causal mechanisms. However, there are some notable differences found between the two field areas.

On the Augusta County fans, Whittecar and Duffy (in press) suggested that the very thick and old F1 fans were deposited by many events over long periods but they were unable to differentiate any separate subunits or widespread depositional events. Although in Nelson County, the oldest deposits (Qf1) are not as thick and continuous, they also appear to be the result of several depositional pulses that cannot be distinguished by weathering criteria. The bases of several very weathered (Qf1) deposits in the study area lie on bedrock (saprolite) surfaces at a variety of elevations. Although the relative age relationships between deposits at these locations are not known, they may each be an alluvial sequence deposited in valleys of different ages. If so, then the Qf1 map unit may consist of a variety of very old valley-fills of different age, just like the F1 mapped in Augusta County.

The most striking difference between the Augusta county and Nelson County fans is the apparent ages of the oldest and intermediate deposits based on soil and weathering criteria. In Nelson County, statistical results of both weathering criteria indicate a large distinction between the youngest surface, Qf3, and older surfaces, Qf1 and Qf2. In Augusta County the oldest deposits were vastly more weathered than the two youngest units.

Many questions come to mind when describing the processes that create these alluvial fans. What might create these alluvial surfaces, and does climate and/or tectonics play a significant role? Is it possible to suggest the ages of the alluvial fans based on comparable data from other works?

Estimate of Relative Age

No radiometric ages exist for the fans in the Stony Creek area. For this reason, we look to compare the data collected in this study to other dated surfaces in order to produce a guesstimate for the ages of these alluvial surfaces. As discussed earlier, the one study that describes soil development criteria with time comes from the Atlantic Coastal Plain, where Markewich et al. (1987, 1989) and Howard et al. (1993) used data from soil profiles developed on dated marine and fluvial deposits that were largely quartzose. The Coastal Plain data for rubbification (soil reddening) and percent clay in the Bt horizon showed broad but usable trends with time that permit order-of-magnitude estimates of soil age (see Figure 4). For example, on quartz-rich Coastal Plain soils a Munsell hue of 2.5 YR is representative of soils with ages between 1 and 10 Ma, while 5.0 YR is representative of soil with ages between 0.1 and 1.0 Ma. At Stony Creek, the older fan surfaces, usually, have soil color of 2.5 YR suggesting an age of greater than one million years. Younger fan surfaces have an average of 10 YR suggesting an age of less than 100,000 years using the Coastal Plain data. Clay percentages described by Markewich et al. (1987, 1989) in well developed soils, dated greater than 1.0 Ma, are small in comparison to those in Nelson County. However, the younger fan surfaces in Nelson County appear much more weathered than those on the Coastal Plain dated greater than 0.1 Ma.

These soil ages for the Stony Creek fans suggested by comparison with Coastal Plain data should be considered maximum ages because of the differences in parent material. The underlying parent materials in the study area are predominately biotite-rich gneisses and pyroxene-bearing granites of the Blue Ridge basement complex rather than quartzose sediments found in the Coastal Plain. These mafic minerals provide a greater amount of weatherable material and clay for soil development.

Another location for comparable analysis is found along the Susquehanna River, where Levine and Ciolkosz (1983) studied weathered till deposits to determine changes in the soils with time. Researchers such as Engel et al. (1996), Mills and Allison (1995), and Whittecar and Ryter (1992) have used soil color and iron oxide content from these Pennsylvanian soil chronosequences for comparable analysis of soils from alluvial surfaces in the Blue Ridge. Soils on the Woodfordian till (15,000 yr. B.P) in Pennsylvania have mean clay percentages of 13% and mean iron oxide percentages of about 1% (Levine and Ciolkosz, 1983). The lower (Qf3) alluvial surfaces in Nelson County have average clay percentages of 25% and iron oxide percentages of 0.5%, and argillic horizons are recognizable in most profiles (Appendix C). Apart from the iron oxide content of the fan surfaces, this comparison suggest an age greater than 15,000 years. Considering the soils in Stony Creek area are derived from fluvial processes initially and contain large amounts of parent material derived from metabasalts, charnokites and biotite-rich gneisses, more weatherable materials are present and may explain the large differences in clay percentages between the two areas (e. g. Mills and Allison, 1995).

Pre-Wisconsinan deposits in Pennsylvania, were suggested as Illinoian age (150 ka to 300 ka) by Gardner et al. (1994) and described as structureless, diamictons by Engel et al. (1996). These deposits have mean clay contents of 32% and mean iron oxide contents of 3.9%. Older fan surfaces, Qf1, in Stony Creek have mean clay contents of 72% and mean iron oxide contents of 3.9%. Parent material from Nelson County contain more readily available weatherable material than found in Pennsylvania, therefore suggesting younger relative ages of the older fan deposits in Virginia, with very high clay content, may not be excessively old, possibly on the order of only several hundred thousand years. These age estimates from younger and older surfaces coincide with estimates considered from the comparison with Coastal Plain deposits.

All of these comparisons suggest that topographically lower surface, Qf3, at Stony Creek is relatively late Pleistocene in age and that higher surfaces, Qf1 and Qf2, are probably early Pleistocene or older in age. The fact that most of the rocks in the older surfaces in Stony Creek are so thoroughly weathered suggests the older surfaces may even be more ancient than early Pleistocene.

Influence of Tectonics

Recent studies in fan formation have directed attention towards the influence of tectonic activity. The most recent tectonic pulse in the Appalachians occurred in the Late Cenozoic (Middle Miocene) (Poag and Sevon, 1989). Appalachian tectonic pulses are recognized by rapid accumulation of marine sediment along the Atlantic Margin, accompanied by latitudinal shifts in the location of depocenters, and finally, regional changes in lithofacies (Poag and Sevon, 1989). Lithospheric flexturing may have accompanied long-term Cenozoic deformation in the Appalachians and Coastal Plain (Gardner, 1989; Pazzaglia, 1993). The Atlantic passive margin lithospheric flexturing was in response to sediment loading in sedimentary basins (i. e. Baltimore Canyon Trough), stress from plate movement, and isostatic deformation in response to continental denudation and water loading of the shelf (Gardner, 1989). Pavich (1986) ascertained that isostatic compensation, or rebound to erosional unloading, has been a controlling factor on the evolution of the Piedmont landscape during the Cenozoic. Cleaves (1989) explained the continued uplift of the Piedmont was documented between the James and Delaware Rivers by distinctive relief and the plateau-like topography, deep narrow valleys of the Potomac and Susquehanna Rivers. Nevertheless, despite this region-wide evidence for Late Cenozoic tectonic activity , no clear evidence of faulting or uplift is known from the study area during the age estimated for the development of the fans.

Influence of Climate

Climatic fluctuations strongly affected northern latitudes in North America during the last 2 million years (Richmond and Fullerton, 1986). Glacial and periglacial regimes spanned approximately 100,000 years and warmer interglacial episodes lasted only 10,000 to 20,000 years (Cleaves, 1989). Analyses of the ^{18}O record from ocean cores indicate that at least eight glaciations covered the Northern Appalachians from Newfoundland to Pennsylvania during the past 0.85 Ma (Braun, 1989). At the height of each glaciation during the Pleistocene, a periglacial geomorphic system appeared to have dominated much of the middle Appalachian area promoting an increase in physical weathering in high elevation stream basins (Pewe, 1983; Clark and Ciolkosz, 1988; Cleaves, 1989; Braun, 1989). The onset of frost action caused by the extreme climatic conditions such as periglaciation may have harvested enough sediment to generate an increase in mass wasting rates in the high altitude valleys because most mountain regions were located above the tree line (Delcourt and Delcourt, 1981; Mills and Delcourt, 1991). In some locations fluvial activity during periglacial conditions produced extensive stream deposits that are now deeply incised by the modern rivers (Clark and Ciolkosz, 1988). However, in other areas deposition by debris flows during catastrophic storms generated major alluvial surfaces, apparently during post-glacial times. During the glacial maxima, the Polar Frontal Zone was well south of Virginia, cold, dry air from the north prevented with warm moist tropical air from moving north, thus decreasing the probability of catastrophic rainfall events (Delcourt, 1980; Kochel, 1987, 1992; Mills and Delcourt, 1991; Whittecar and Duffy, 1997). In Holocene time, tropical storms and related catastrophic floods have caused major landslides and debris flows within narrow valleys along the Blue Ridge (Clark, 1987; Jacobson et al., 1989). Kochel and Johnson (1984) suggested fan deposition along the footslopes of the Blue Ridge was episodic over many thousands of years, but that major deposition occurred during times of severe climate changes such as during periglacial-to-interglacial transitions. The abundant slope debris produced by mechanical weathering would be very unstable during the abundant storms of interglacial periods.

Thus Pleistocene climate changes could have caused the multiple alluvial surfaces in Nelson County. Extensive mass wasting most probably occurred during transitions between periglacial and interglacial conditions and could have caused the deposition of many of the fan deposits. The lack of stratification, particularly in the older fan sediments suggests rapid deposition over short time periods. However, without absolute age determinations for the fan surfaces, the precise timing and cause of fan formation cannot be determined.

CHAPTER V

SUMMARY AND CONCLUSIONS

The alluvial surfaces in the study area occur as coalescing fan complexes, consisting of four separate generations of topographically distinct alluvial surfaces built mostly of differentially weathered greenstone gravels. The oldest fan surfaces (Qf1) directly overlie saprolite at many sites. Matrix-supported pebble-to-cobble deposits dominate the unit indicating deposition by debris flow. Differences in elevation between several sample sites that contain the Qf1 deposits may indicate multiple cut-and-fill episodes, possibly over an extended period of time. Distinctions between these deposits on Qf1 surfaces are difficult because of the advanced states of downcutting and the dissection from small tributaries of the Rockfish River. Eventually, the Qf1 surfaces were isolated into remnants of highly weathered materials that are now found on hilltops. The Qf1 surfaces display red colors, high clay and iron content, and extremely weathered cobbles. Comparison of these features with previous studies on deposits with better age control elsewhere in the eastern U. S. suggests the time of deposition of the Qf1 deposits was early Pleistocene or older.

Intermediate-age surfaces, Qf2, are located on mid-elevation terraces. These terraces contain mostly matrix-supported pebble-to-cobble debris flow deposits. The soils on these surfaces contain red-to-orange colors, high clay and iron contents. Clasts within these Qf2 deposits contain a mixture of thick and thin weathering rinds. This range of rind thicknesses may indicate either of the pre-weathered Qf1 clasts into Qf2 deposits during the process of Qf2 fan formation or differential weathering based on clast mineralogy. Between upper (Qf1) and middle surfaces (Qf2) soil development characteristics are somewhat similar but not as discriminating as weathering rinds. Because of these statistical similarities the age difference between the upper and middle surfaces appears small using the soil data, yet the topographic and weathering rind data indicate a greater difference in age. The large amount of soil and rind development in Qf1 and Qf2 surfaces indicates either rapid soil and rind development or a significant amount of time went by before the deposition of the younger, Qf3, surfaces.

As the drainage system within the Rockfish Valley shifted position over time from the northeast to the southwest, numerous bedrock (saprolite) valleys were incised and filled with Qf1 deposits. After this system created a large lowland area, a major episode of fan accumulation formed the widespread Qf2 surface in this valley. Thus the geomorphic and weathering data suggest that the Qf2 deposits are significantly younger than Qf1 deposits but are also "early Pleistocene or older" in age.

Stream dissection and erosion continued as aggradational processes deposited Qf3 surfaces. Younger surfaces, Qf3, are located closest to the mountain front and extend along the eastern most margins of Stony Creek. The lower surfaces surround both middle and upper fan surfaces of the complex but are not as laterally extensive as the previously active fans. Clast-supported, cobble-to-boulder stream sediments are strongly imbricated in these terrace deposits. These lower surfaces contain deposits with relatively little clay or iron and with yellow-to-brown colors. These data suggest the Qf3 deposits were deposited by fluvial flow during late Pleistocene or Holocene.

The most recent deposit, Qal, is the floodplain located closest to the mountain front and Stony Creek. Clast-supported, cobble-to-boulder stream sediments are strongly imbricated in these floodplain deposits. Stony Creek developed this surface in its present day position. Qal is the only active alluvial surface found in the field area today.

Whittecar and Duffy (in press) concluded that tectonic events during the Tertiary (mid-Miocene) and climatic changes during the Quaternary formed the alluvial fan surfaces on the opposite (western) side of this portion of the Blue Ridge Mountains. The fans and exposures in the present study area are not as extensive as those in the previous study, so the sedimentary and geomorphic data are less complete. Even so, great similarities exist in weathering characteristics, stratigraphic succession and geomorphic histories of the two study areas. The major differences occur between soil development and clast weathering rind features, all of which can be attributed to differences in source rock lithology (quartzites vs. greenstone-and-charnokite). Thus the geomorphic evidence from alluvial fans on the eastern side of the Blue Ridge Mountains in central Virginia supports the interpretation of fan formation previously developed on the western side.

REFERENCES

Badger, R. L., 1993, Fluid Interaction and Geochemical Mobility in Metabasalts: An Example From the Central Appalachians: Journal of Geology, v. 101, p. 85-95.

Bartholomew, M. J., 1977, Geology of the Greenfield and Sherando Quadrangles, Virginia: Virginia Division of Mineral Resources, Publication 4, 43 p.

Blair, T. C., and McPherson, J. G., 1994, Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages: Journal of Sedimentary Research, v. A64, p. 451-490.

Braun, D. D., 1989, Glacial and periglacial erosion of the Appalachians: Geomorphology, v. 2, p. 233-256.

Carter, M. R., 1993, Soil physical analyses, *in* Soil sampling and methods of analysis, Boca Rotan, p. 507-509.

Chittleborough, D. J. and Walker, P. H., 1988, Crystallinity of soil kaolinites in relation to clay particle-size and soil age: Journal of Soil Science, v. 39, p. 81-86.

Clark, G. M., 1987, Debris slide and debris flow historical events in the Appalachians south of the glacial border: Geological Society of America: Reviews in Engineering Geology, v. 7, p. 125-138.

Clark, G. M. and Ciolkosz, E. J., 1988, Periglacial geomorphology of the Appalachian highlands and interior highlands south of the glacial border-a review: Geomorphology, v. 1, p. 191-220.

Cleaves, E. T., 1989, Appalachian Piedmont landscapes from Permian to the Holocene: Geomorphology, v.2, p. 159-179.

Colman, S. M., 1981, Rock-weathering rates as functions of time: Quaternary Research, v.15, p. 250-264.

———, and Pierce, 1981, Weathering rinds on andesitic and basaltic stones as a Quaternary age indicator, western United States: Geological Survey Professional Paper, 1210, 40 p.

Costa, J. E., 1988, Rheologic, geomorphic, and sedimentologic differentiation of water floods, hyperconcentrated flows, and debris flows *in* Baker, V. R., Kochel, C. R., and Patton, P. C., eds., Flood Geomorphology, Wiley, New York, p. 113-122.

Darby, D. A., Whittecar, G. R., Barringer, R. A., and J. R. Garrett, 1990, Alluvial fan lithofacies recognition in a humid-tropical setting: Sedimentary Geology, v. 67, p. 167-174.

Davis, J. C., 1986, Statistics and data analysis in geology (2nd ed.), Wiley, New York, p. 478-515.

Day, P. R., 1965, Particle fractionation and particle-size analysis *in* Black, C. L., ed., Methods of Soil Analysis Part 1, Madison, Wisconsin, p. 545-567.

Delcourt, P. A., 1980, Landscape response to Quaternary climate change in east Tennessee: Geological Society of America Abstracts with Programs, v. 12, p. 411.

———, and Delcourt, H. R., 1981, Vegetation maps for eastern North America; 40,000 y B. P. to the present, *in* Romans, R. C., ed., Geobotany II, Plenum, p. 123-165.

Duffy, D. L. 1991, The geomorphology of alluvial fan deposits on the west flank of the Blue Ridge, Augusta County, Virginia. M.S. thesis, Old Dominion University, Norfolk, 118 p.

Engel, S. A.; Gardner, T. W.; and Ciolkosz, E. J., 1996, Quaternary soil chronosequences on terraces of the Susquehanna River, Pennsylvania: Geomorphology, v. 17, p. 273-294.

Foth, H. D.; Withee, L. V.; Jacobs, H. S.; and S. J. Thien, 1982, Laboratory Manual for Introductory Soil Science. W.C. Brown: Dubuque, 143 p.

Gardner, T. W., 1989, Neotectonism along the Atlantic passive continental margin: a review: Geomorphology, v. 2, p. 71-97.

———, Sasowsky, I. D.; and Schmidt, V. A., 1994, Reversed-polarity glacial sediments and revised glacial chronology, West Branch Susquehanna River Valley, central Pennsylvania: Quaternary Research, v. 42, p. 131-135.

Gathright, T. M., 1976, Geology of the Shenandoah National Park, Virginia: Virginia Division of Mineral Resources Bulletin 86, 93 p.

Gee, G. W., and Bauder, J. W., 1979, Particle size analysis by hydrometer: a simplified method: Soil Science Society of America Journal, v. 43, p. 1004-1007.

Gerrard, A. J., 1994, Weathering of granitic rocks: environment and clay mineral formation, *in* Robinson, D. A., and Williams, R. G. B., Rock Weathering and Landform Evolution: Wiley, New York, p. 3-20.

Hack, J. T., 1982, Physiographic divisions and differential uplift in the Piedmont and Blue Ridge: U. S. Geological Survey Professional Paper 1265, 49 p.

Howard, J. L.; Amos, D. F.; and Daniels, W. L., 1993, Alluvial soil chronosequence in the Inner Coastal Plain, Central Virginia: Quaternary Research, v. 39, p. 201-213.

Jacobson, R. B.; Miller, A. J.; and Smith, J. A., 1989, The role of catastrophic geomorphic events in central Appalachian landscape evolution: Geomorphology, v. 2, p. 257-284.

Jackson, M. L.; Lim, C. H.; and Zelazny, L. W., 1986, Oxides, Hydroxides, and Aluminosilicates in Klute, A. (Ed.), Methods of soil analysis, #9, Part 1, Physical and mineralogical methods (2nd ed.): Madison, Soil Science Society of America, p.122-123.

Knuepfer, P. L. K., 1988, Estimating ages of late Quaternary stream terraces from analysis of weathering rinds and soils: Geological Society of America Bulletin, v. 100, p. 1224-1236.

Kochel, R. C., 1987, Holocene debris flows in central Virginia *in* J.E. Costa and G. F. Wieczorek (eds.), Debris flows/avalanches: Process, recognition and mitigation. Geological Society of America Reviews in Engineering Geology Volume VII, p.139-155.

———, 1990, Humid Fans of the Appalachian Mountains, *in* Rachocki, A. H., and Church, M., eds., Alluvial Fans: A Field Approach, Wiley, New York, p. 109-129.

———, and Johnson, R.A., 1984, Geomorphology and sedimentology of humid-temperate alluvial fans, central Virginia. *in* Sedimentology of Gravels and Conglomerates: Koster E. H. and Steel, R. J. (eds.), Canadian Society of Petroleum Geologists, Memoir 10, p. 109-122.

———, 1992, Geomorphology of alluvial fans in west-central Virginia, *in* Whittecar, G. R., ed., Alluvial fans and boulder streams of the Blue Ridge Mountains, west-central Virginia: Southeastern Friends of the Pleistocene 1992 Field Trip Guidebook, p. 47-60.

Kovach, W. L., 1988, Multivariate methods of analyzing paleoecological data: Special Publication – The Paleontological Society, v. 3, p. 72-104.

Lal, D.; Barg, E.; Jull, A. J. T.; Pavich, M. J.; Southon, J.; Caffee, M. W.; and Finkel, R. C., 1997, Cosmogenic nuclear methods for determining soil erosion and formation rates: American Geological Institute, v. STI/PUB/908, p. 95-99.

Levine, E. R., and Ciolkosz, E. J., 1983, Soil development in tills of various ages in Northeastern Pennsylvania: Quaternary Research, v. 19, p. 85-99.

Mack, G. H., and James, W. C., 1992, Paleosols for Sedimentologists: Geological Society of America Short Course Notes, p. 25-38.

Markewich, H. W., Pavich, M.J., Mausbach, M.J., Hall, R. L., Johnson, R. G. and Hearn, R. P., 1987, Age relationships between soils and geology in the coastal plain of Maryland and Virginia: U. S. Geological Survey Professional Paper 1581-a, 34 p.

———; ———; Mausbach, M. J.; Johnson, R. G.; and Gonzalez, V. M., 1989, A guide for using soil and weathering profile data in chronosequence studies of the Coastal Plain of the Eastern United States: U. S. Geological Survey Bulletin 1589, 39 p.

Mills, H. H., 1987, Debris slides and foot-slope deposits in the Blue Ridge Province *in* W. L. Graf (ed.), Geomorphic Systems of North America: Centennial Special Volume 2, Geological Society of America, p.29-37.

———, and Delcourt, P. A., 1991, Quaternary geology of the Appalachian Highlands and Interior Low Plateaus: Geology of North America, v. k-2, p. 611-628.

———, and Allison, J. B., 1995, Weathering and soil development on fan surfaces as a function of height above modern drainageways, Roan Mountain, North Carolina: Geomorphology, v. 14, p. 1-17.

———, and ———, 1995, Weathering rinds and the evolution of piedmont slopes in the southern Blue Ridge Mountains: Journal of Geology, v. 103, p. 379-394.

NRCS, in press, Soil survey of Nelson County, Virginia: U. S. Department of Agriculture, National Resource Conservation Survey in cooperation with Virginia Polytechnic Institute and State University.

Pavich, M. J., 1989, Regolith residence time and the concept of surface age of the Piedmont "Peneplain": Geomorphology, v. 2, p. 181-196.

Pazzaglia, F. J., 1993, Stratigraphy, petrography, and correlation of late Cenozoic middle Atlantic Coastal Plain deposits: Implications for late-stage passive-margin geologic evolution: Geological Society of America Bulletin 105, p. 1617-1634.

Peatross, J. L., 1986, A morphometric study of slope stability controls in central Virginia: Masters thesis, University of Virginia, 150 p.

Pewe, T. L., 1983, Periglacial environment in North America during Wisconsin Time: Late Quaternary Environments of the United States, *in* Wright, H. E., Jr. ed., The Late Pleistocene, Porter, C. C., ed., University of Minnesota Press, Minneapolis, p. 157-188.

Poag, C. W., and Sevon, W. D., 1989, A record of Appalachian denudation in postrift Mesozoic and Cenozoic sedimentary deposits of the U. S. Middle Atlantic Continental Margin: Geomorphology, v. 2, 119-157.

Retallack, Greg, 1988, Field recognition of paleosols: Geological Society of America Special Paper 216, 20 p.

Richmond, G. M. and Fullerton, D. S., 1986, Summation of Quaternary glaciation in the U. S. of America, *in* Sibrava, I.; Bowen, D. Q.; and Richmond, G. M., eds., Quaternary glaciations in the Northern Hemisphere, Quaternary Science Reviews 5, p. 183-196.

Ritter, J. B.; Miller, J. R.; Enzel, Y.; and Wells, S. G., 1995, Reconciling the roles of tectonism and climate in Quaternary alluvial fan evolution: Geology, v. 23, p. 245-248.

Schwarz, F. K., 1970, The unprecedented rains in Virginia associated with the remnants of hurricane Camille: Monthy Weather Review, v. 98, p. 851-859.

Singer, M. J., and Janitzky, P., 1986, Field and laboratory procedures used in a soil chronosequence study: U. S. Geological Survey Bulletin 1648, 49 p.

Simmons, D. W., 1988, Geomorphology and sedimentology of humid-temperate alluvial fans along the west flank of the Blue Ridge Mountains, Shenandoah Valley, Virginia. M.S. thesis, Southern Illinois University, Carbondale, 107 p.

Virginia Division of Mineral Resources, 1969, Natural features caused by a catastrophic storm in Nelson and Amherst counties, Virginia: Virginia Minerals, Special Issue, 20 p.

Wayne, D. M., and Sinha, A. K., 1992, Stability of Zircon U-Pb Systematics in a Greenschist-Grade Mylonite: An Example from the Rockfish Valley Fault Zone, central Virginia, USA: Journal of Geology, vol.100, p. 593-603.

Webb, H. W., Nunan, W. E., and Penley, H. M., 1970, Road-log storm-damaged areas in central Virginia: Virginia Minerals, v. 16, no.1. p. 1-10.

Whitehouse, I. E.; Knuepfer, P. L. K.; McSaveney, M. J. and Chinn, T. J. H., 1986, Growth of weathering rinds on Torlesse Sandstone, Southern Alps, New Zealand, *in* Colman, S. M., and Dethier, D. P. eds., Rates of Chemical Weathering of Rocks and Minerals: Academic Press, New York, p. 419-435.

Whittecar, G.R., and Ryter, D. W., 1992, Quaternary boulder streams and debris fans of the Blue Ridge, Augusta Co., Virginia. *in* Alluvial Fans and Boulder Streams of the Blue Ridge Mountains, West-Central Virginia, Whittecar, G.R. (ed.). Field Trip Guidebook Southeastern Friends of Pleistocene, Old Dominion University, p. 61-78.

———, and Duffy D. F., 1993, Geomorphology and stratigraphy of late Cenozoic alluvial fans, Augusta Co., Virginia *in* Alluvial Fans and Boulder Streams of the Blue Ridge Mountains, West-Central Virginia, Whittecar, G.R. (ed.). Field Trip Guide book Southeastern Friends of Pleistocene, Old Dominion University, p. 79-112.

———, and ——— (In press). Geomorphology and stratigraphy of Late Cenozoic alluvial fans, Stuarts Draft, Virginia, U. S. A. *in* G. M. Clark (ed.), Regolith in the Appalachian Highlands South of the Glacial Border. Geological society of America Special Paper.

Woodward, J. C.; Macklin, M. G.; and Lewin, J., 1994, Pedogenic weathering and relative-age dating of Quaternary alluvail sediments in the Pindus Mountains of Northwest Greece, *in* Rock Weathering and Landform Evolution: Robinson, D. A., and Williams, R. B. G., eds., Wiley, New York, p. 259-283.

APPENDIX A

Particle Size Analysis Procedure

A modified hydrometer method (Carter, 1993; Day, 1965; Foth and other, 1982; Gee and Bauder, 1979) to determine the percentage of 4 μm clay in the less-than-2mm fraction of the matrix samples collected from each soil profile:

1. Soil samples were collected for laboratory analysis at 0.5 to 1 foot intervals, depending on the size of the exposure.

2. Weigh sample into 250 ml screw cap bottle, add 100 ml of deionized water and 10 ml of sodium hexametaphosphate.

3. Remove samples, disperse in blender for one to two minutes, if necessary.

4. Wet sieve the sample, using deionized water, through a 0.0625 mm (4 ϕ) sieve into a 1000 ml beaker, making sure not to exceed 900 ml.

5. Transfer the sieved material into a 1000 ml settling tube and add deionized water to the fill tube to 1000 ml.

6. Rinse sand fraction into a 100 ml beaker and allow to settle. Decant excess water and dry in oven, overnight at 105 ° C. Allow sample to cool and weigh sand.

7. When prepared for analysis, stir contents of settling tube with an agitation rod using smooth up and down motion, careful not to splash sample. Stop stirring after one minute and start timer. Do not restir after this point. Take the first reading after 40 seconds, this is the silt and clay fraction in suspension.

8. Take the second reading after 8 hours has past. This is the 4 μm clay fraction.

9. After both reading are taken, the following equation are used to determine the sand, silt and clay ratios in the sample:

   % sand = (weight of the < 2 mm fraction (step 6) / total dry sample weight) x 100

   % clay = (weight of 4 μm clay fraction (step 8) / total dry sample weight) x 100

   % silt = 100 - % sand - % clay

APPENDIX B

Particle Size Data

DEPTH METERS	% SAND	% SILT	% CLAY	COLORS
SITE RC1: AUGER HOLE				
0.3	14	19	67	5YR4/6
0.6	16	20	64	5YR4/6
0.9	16	13	71	5YR4/6
1.2	15	9	76	5YR4/8
1.5	17	12	71	5YR4/6
SITE BW2: BACK HOE PIT				
0.3	14	29	57	5YR4/4
0.6	14	19	67	2.5YR4/6
0.9	10	13	77	2.5YR4/8
1.2	9	19	72	2.5YR4/8
1.5	11	22	67	2.5YR4/8
SITE FD12: AUGER HOLE				
0.3	13	4	83	2.5YR4/6
0.6	14	4	82	2.5YR5/8
0.9	25	8	67	2.5YR4/8
1.2	38	8	54	2.5YR4/6
1.5	36	1	63	2.5YR5/8
SITE FD1: AUGER HOLE				
0.15	22	31	47	2.5YR4/6
0.3	31	21	48	2.5YR4/6
0.45	34	22	44	2.5YR4/8
0.75	30	30	40	2.5YR4/6
0.9	27	28	45	2.5YR4/8
1.2	23	23	54	2.5YR4/6
SITE FD2: AUGER HOLE				
0.15	28	21	51	2.5YR3/6
0.3	22	27	51	5YR4/6
0.45	26	30	44	5YR4/6
0.6	24	31	45	5YR5/8
0.75	24	32	44	7.5YR4/6
0.9	36	20	44	7.5YR5/8
1.05	19	41	40	7.5YR5/6
1.2	36	41	23	10YR5/6
SITE FD3: BACK HOE PIT				
0.3	16	18	66	7.5YR5/8
0.6	19	20	61	7.5YR5/8
0.9	30	16	54	
1.2	29	21	50	
1.5	39	15	46	

DEPTH METERS	% SAND	% SILT	% CLAY	COLORS
SITE FD4: BACK HOE PIT				
0.3	20	18	62	2.5YR4/6
0.6	18	14	68	2.5YR4/8
0.9	17	14	69	2.5YR4/8
1.2	18	10	72	2.5YR4/6
1.5	27	15	58	2.5YR4/8
SITE CP1: AUGER HOLE				
0.15	17	19	64	10R3/6
0.3	14	19	67	10R3/4
0.45	16	12	72	10R3/6
0.6	19	15	66	10R3/6
0.75	22	17	61	2.5YR3/6
0.9	35	13	52	10R4/6
1.05	34	16	50	10R4/6
1.2	36	17	47	2.5YR4/6
SITE CP2: AUGER HOLE				
0.3	19	18	63	2.5YR4/8
0.6	16	20	64	10R4/8
0.9	16	12	72	10YR4/8
1.2	20	7	73	10R4/6
SITE CP3: AUGER HOLE				
0.3	35	28	37	5YR3/4
0.6	22	24	54	5YR4/6
0.9	23	17	60	5YR5/6
1.2	23	15	62	7.5YR5/8
1.5	36	8	56	7.5YR5/6
SITE CP4: BACK HOE PIT				
0.3	15	18	67	5YR4/6
0.6	16	24	60	5YR5/8
0.9	18	12	70	5YR5/8
1.2	18	14	68	5YR4/6
1.5	22	13	65	5YR5/8
1.8	25	10	65	
SITE LV1: BACK HOE PIT				
0.3	15	25	60	2.5YR4/6
0.6	15	19	66	2.5YR4/6
0.9	15	13	72	2.5YR4/8
1.2	15	7	78	2.5YR4/6
1.5	18	11	71	2.5YR4/6

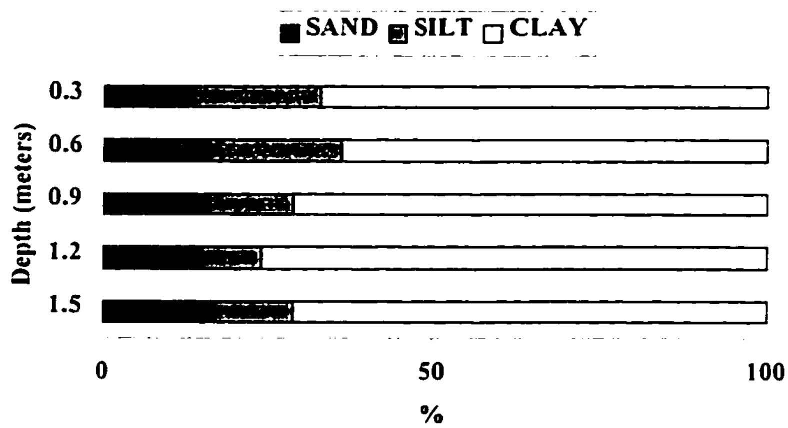
SITE LV3: STREAM CUT

DEPTH METERS	% SAND	% SILT	% CLAY	COLORS
0.3	20	17	63	2.5YR4/6
0.6	36	14	50	2.5YR4/6
0.9	30	20	50	2.5YR4/6
1.2	26	18	56	2.5YR4/4
1.5	27	17	56	2.5YR4/4
SITE MID2: STREAM CUT				
0.3	81	3	16	10YR5/6
0.6	85	0	15	10YR6/8
0.9	77	7	16	10YR6/6
SITE MID1: BACK HOE PIT				
0.3	50	22	28	10YR3/6
0.6	51	28	21	7.5YR4/6
0.9	36	32	32	10YR4/6
1.2	64	16	20	7.5YR4/6
1.5	62	0	38	7.5YR3/4
SITE REC1: BACK HOE PIT				
0.3	49	22	29	10YR3/4
0.6	61	10	29	7.5YR4/6
0.9	66	2	32	7.5YR5/8
1.2	71	3	26	10YR5/8
1.5	73	3	24	10YR5/6

APPENDIX C

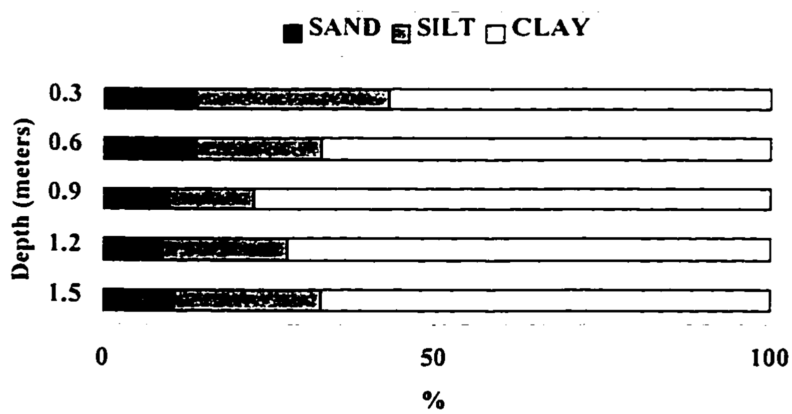
Soil Profiles For Particle Size Data In Appendix B

Site RC1

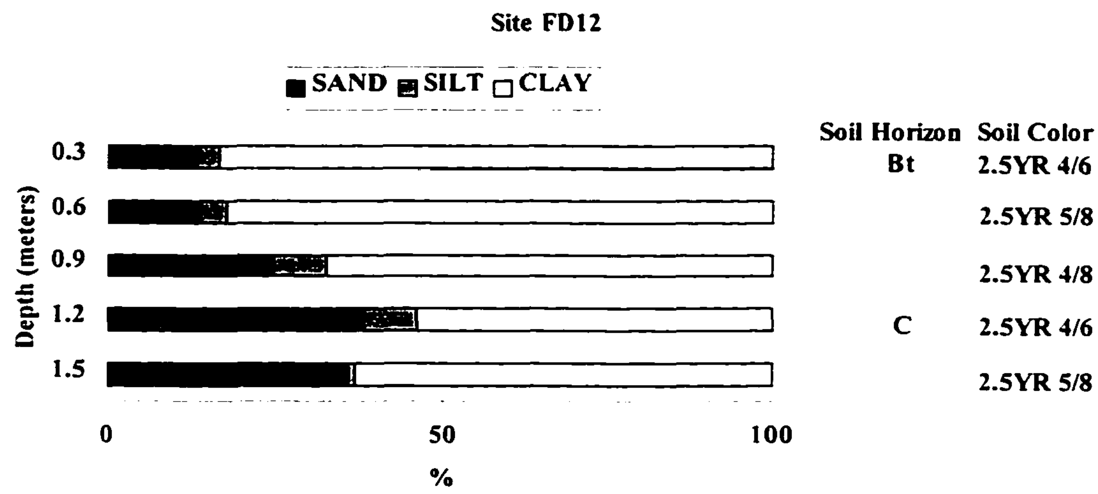


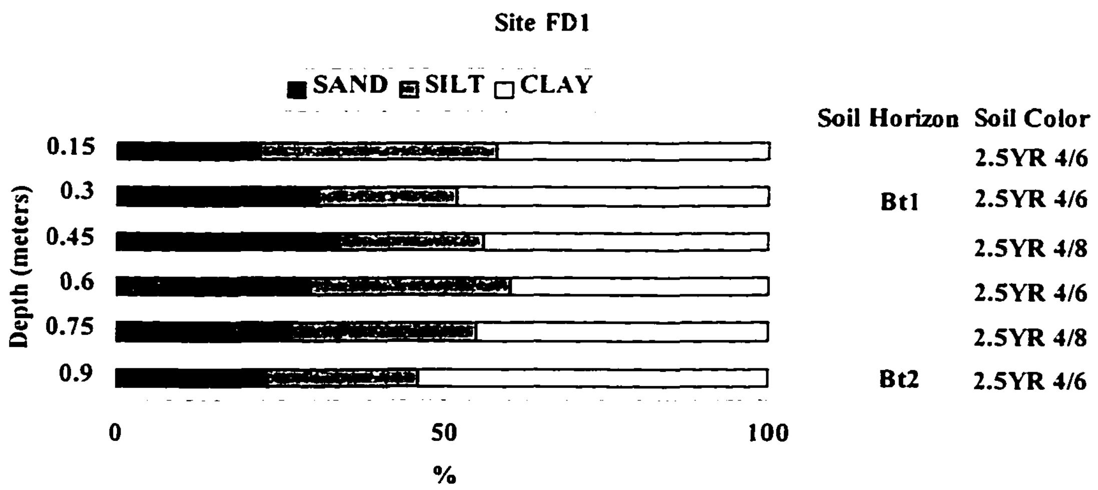
Soil Horizon	Soil Color
	5YR 4/6
	5YR 4/6
	5YR 4/6
Bt	5YR 4/8
	5YR 4/6

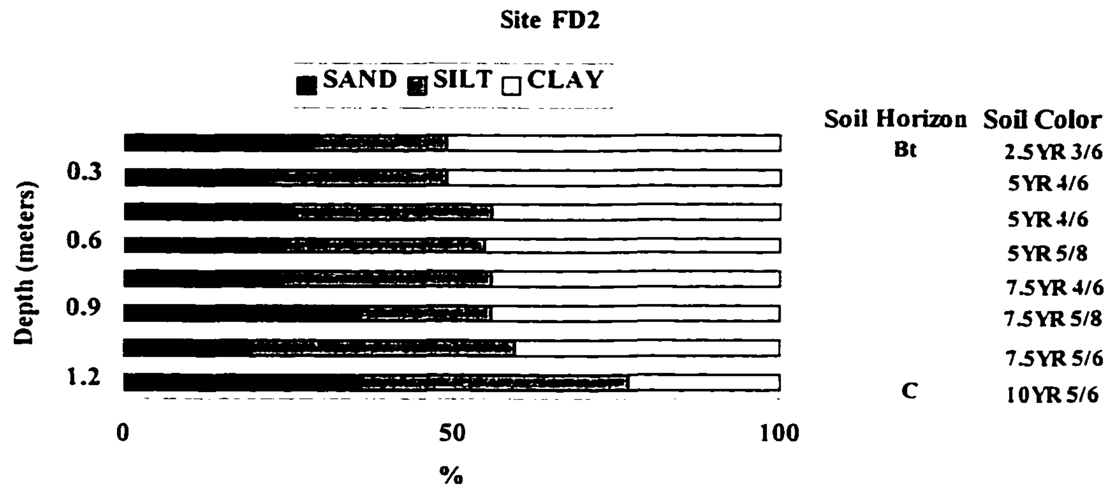
Site BW2

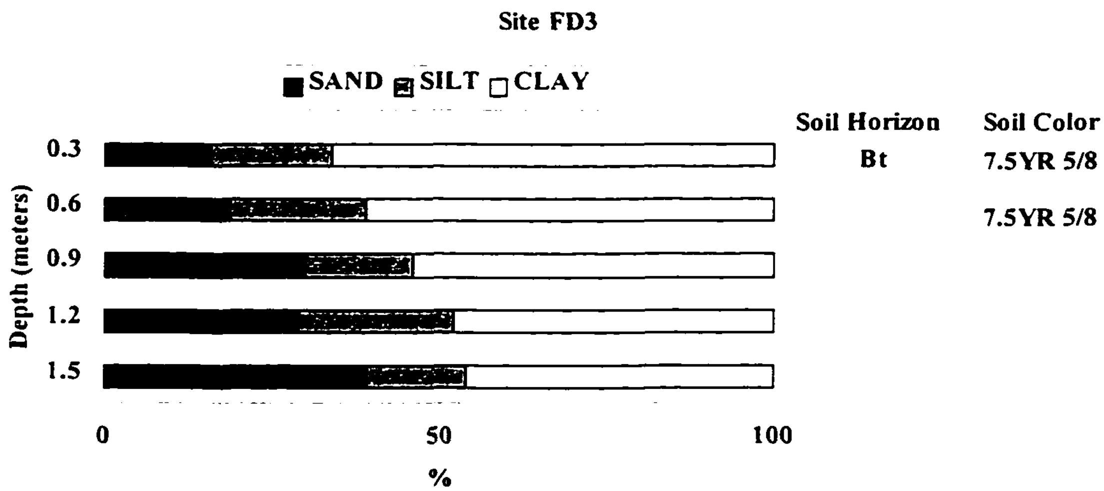


Soil Horizon	Soil Color
Ap	5YR 4/4
	2.5YR 4/6
Bt	2.5YR 4/8
	2.5YR 4/8
	2.5YR 4/8

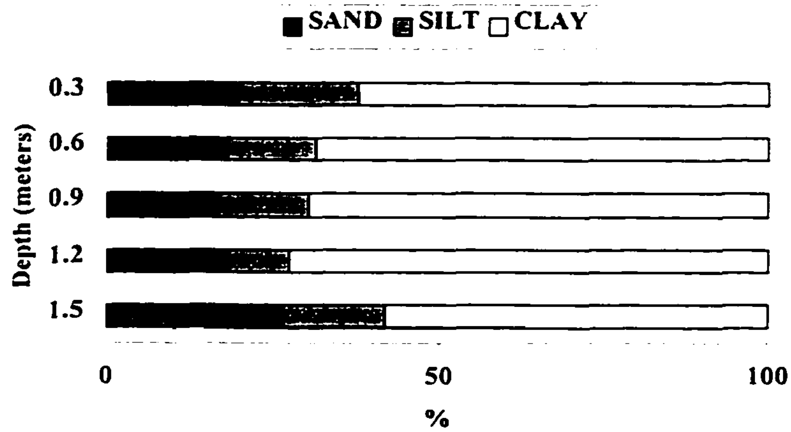

Site FD12
SAND
SILT
CLAY
Soil Horizon
Soil Color
Bt
2.5YR 4/6
2.5YR 5/8
2.5YR 4/8
C
2.5YR 4/6
2.5YR 5/8
Depth (meters)
0.3
0.6
0.9
1.2
1.5
0
50
100
%


Site FD1
SAND
SILT
CLAY
Soil Horizon
Soil Color
2.5YR 4/6
Bt1
2.5YR 4/6
2.5YR 4/8
2.5YR 4/6
2.5YR 4/8
Bt2
2.5YR 4/6
Depth (meters)
0.15
0.3
0.45
0.6
0.75
0.9
0
50
100
%


Site FD2
SAND SILT CLAY
Soil Horizon
Soil Color
Bt
C
2.5YR 3/6
5YR 4/6
5YR 4/6
5YR 5/8
7.5YR 4/6
7.5YR 5/8
7.5YR 5/6
10YR 5/6
Depth (meters)
0.3
0.6
0.9
1.2
0
50
100
%

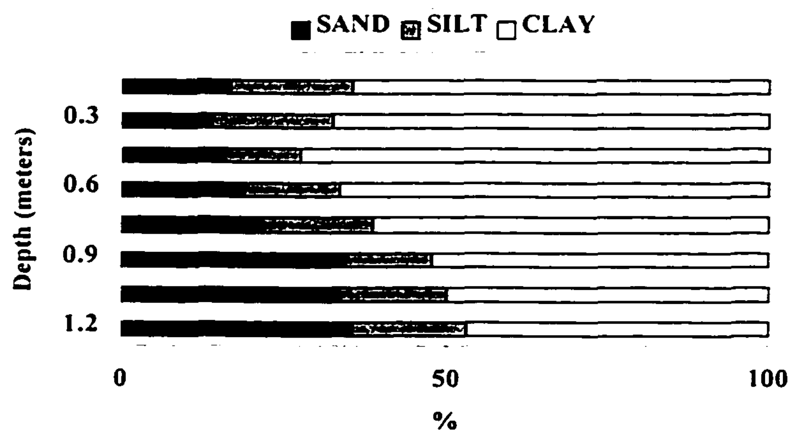

Site FD3
SAND SILT CLAY
Soil Horizon
Soil Color
Bt
7.5YR 5/8
7.5YR 5/8
Depth (meters)
0.3
0.6
0.9
1.2
1.5
0
50
100
%

Site FD4



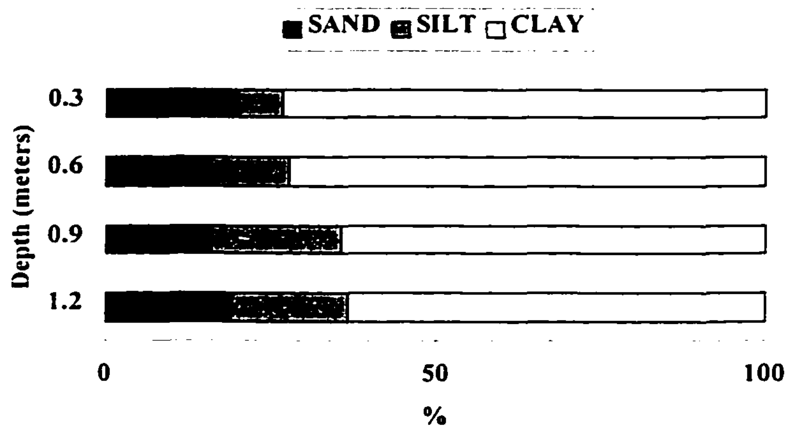
Soil Horizon	Soil Color
Ap	2.5YR 4/6
	2.5YR 4/8
Bt	2.5YR 4/8
	2.5YR 4/6
	2.5YR 4/8

Site CP1



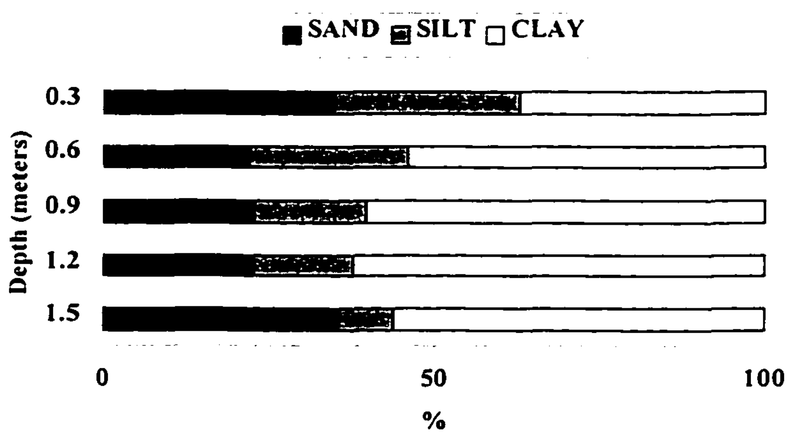
Soil Horizon	Soil Color
Bt1	10R 3/6
	10R 3/4
	10R3/6
	10R 3/6
	2.5YR 3/6
Bt2	10R 4/6
	10R 4/6
	2.5YR 4/6

Site CP2



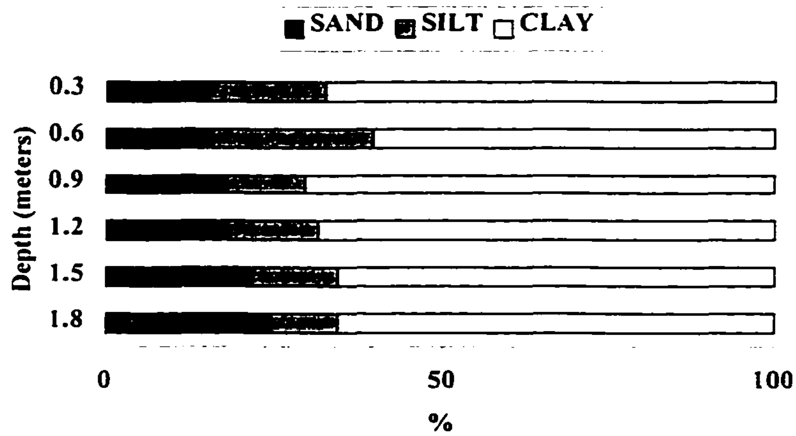
Soil Horizon	Soil Color
Bt	10R 4/6
	10R 4/8
	10R 4/8
	2.5YR 4/8

Site CP3



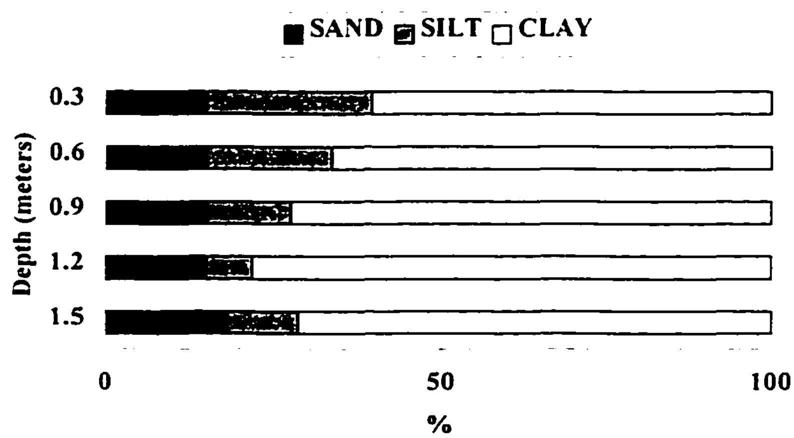
Soil Horizon	Soil Color
A	5YR 3/4
	5YR 4/6
Bt	5YR 5/6
	7.5YR 5/8
C	7.5YR 5/6

Site CP4

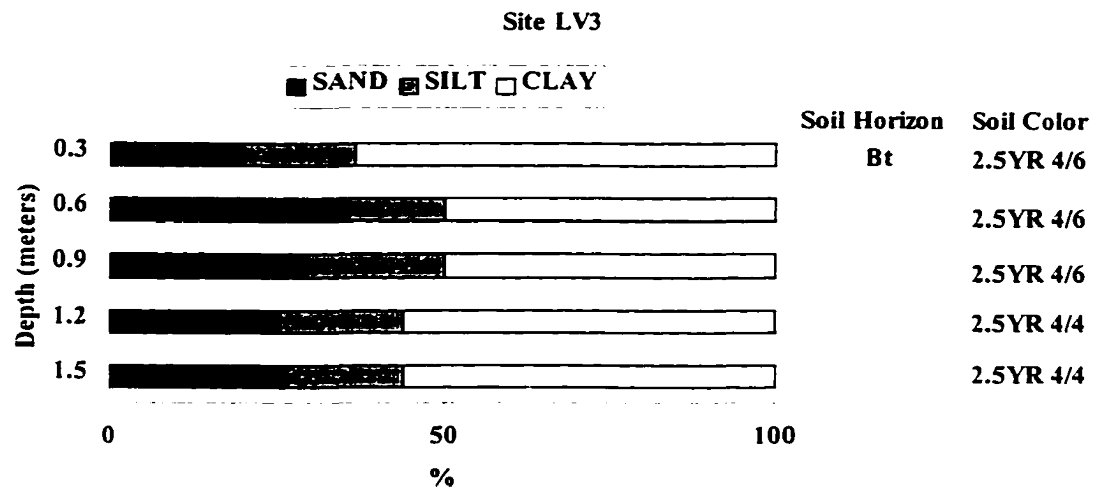


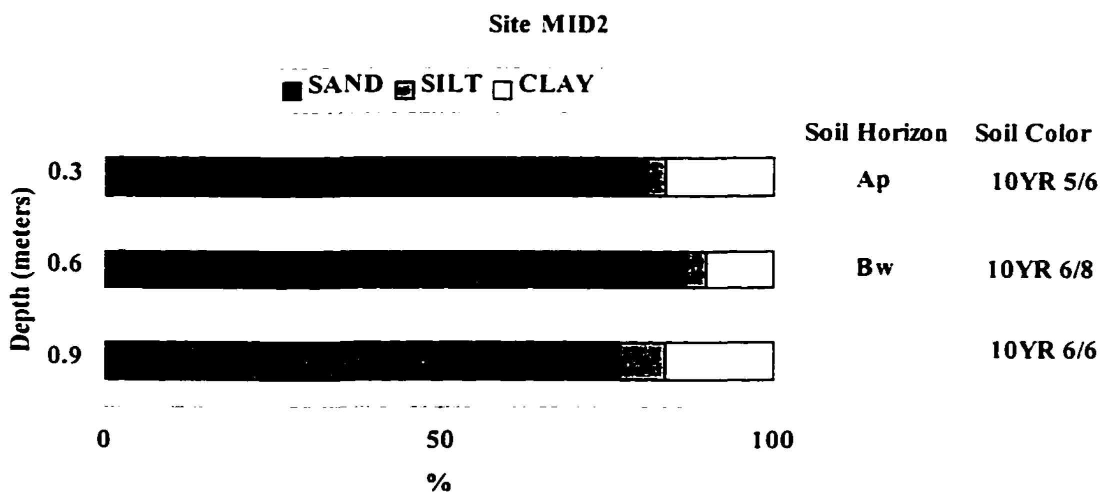
Soil Horizon	Soil Color
	5YR 4/6
	5YR 5/8
Bt	5YR 5/8
	5YR 4/6
	5YR 5/8
BC	7.5YR 5/8

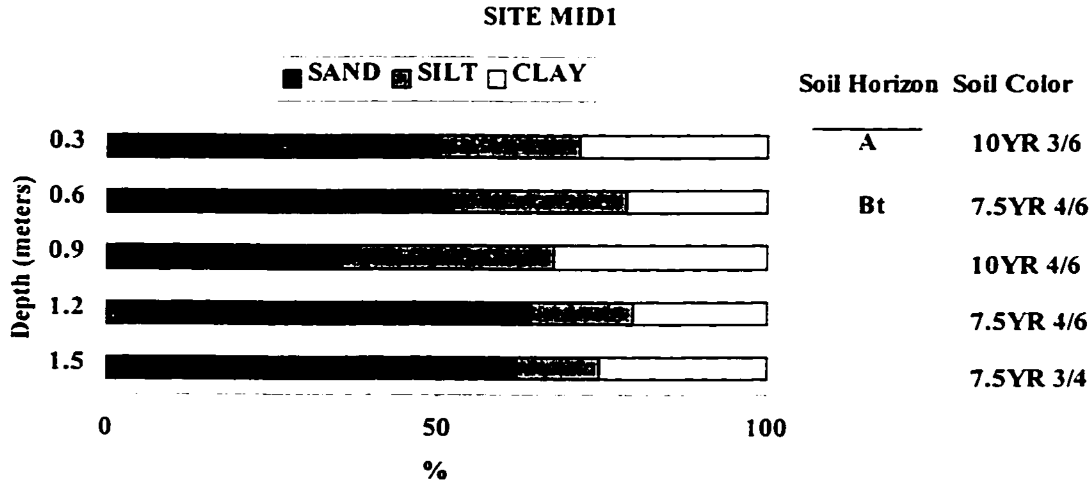
Site LV1

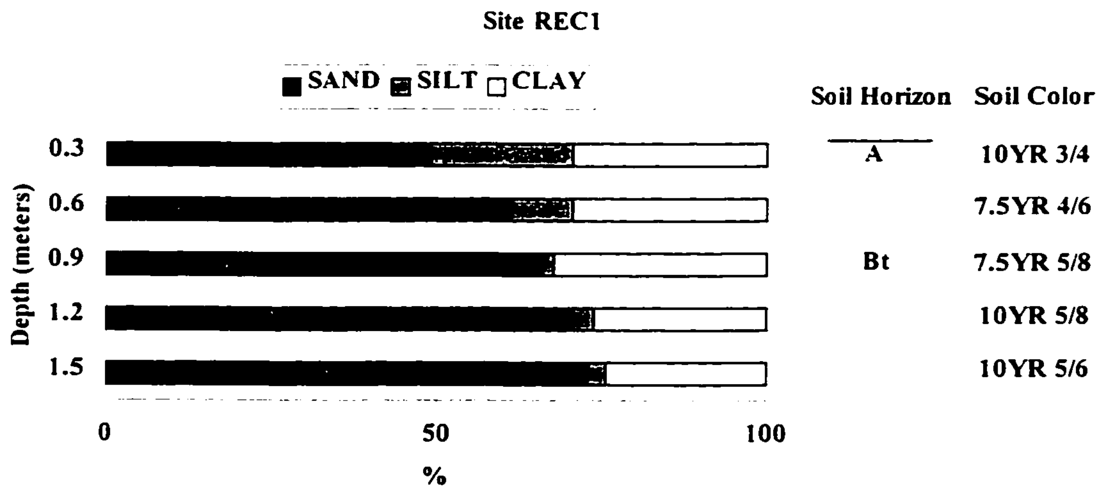


Soil Horizon	Soil Color
Bt1	2.5YR 4/6
	2.5YR 4/6
	2.5YR 4/8
Bt2	2.5YR 4/6
	2.5YR 4/6


Site LV3
SAND SILT CLAY
Soil Horizon
Soil Color
Bt
2.5YR 4/6
2.5YR 4/6
2.5YR 4/6
2.5YR 4/4
2.5YR 4/4
Depth (meters)
0.3
0.6
0.9
1.2
1.5
0
50
100
%


Site MID2
SAND SILT CLAY
Soil Horizon
Soil Color
Ap
10YR 5/6
Bw
10YR 6/8
10YR 6/6
Depth (meters)
0.3
0.6
0.9
0
50
100
%


SITE MID1
SAND
SILT
CLAY
Soil Horizon
Soil Color
Depth (meters)
0.3
0.6
0.9
1.2
1.5
A
Bt
10YR 3/6
7.5YR 4/6
10YR 4/6
7.5YR 4/6
7.5YR 3/4
0
50
100
%


Site REC1
SAND
SILT
CLAY
Soil Horizon
Soil Color
Depth (meters)
0.3
0.6
0.9
1.2
1.5
A
Bt
10YR 3/4
7.5YR 4/6
7.5YR 5/8
10YR 5/8
10YR 5/6
0
50
100
%

APPENDIX D

Data Used In Statistical Analysis

Soil Weathering Criteria

Sample Site/Map Unit	Max Clay %	Color	Fe %	Height Above Stream (m)
Mid2/Qf3	10	10 YR	0	1.41
Mid1/Qf3	32	10 YR	0.84	1.93
Rec1/Qf3	32	7.5 YR	0.44	2.83
Bw2/Qf2	77	2.5 YR	5.39	2.23
Fd2/Qf2	51	2.5 YR	4.84	14.57
Fd4/Qf2	69	2.5 YR	4.03	4.80
Lv1/Qf2	72	2.5 YR	3.82	10.91
Lv3/Qf2	63	2.5 YR	4.6	7.34
Fd12/Qf1	82	2.5 YR	4.84	29.97
Cp1/Qf1	72	10 R	5.09	27.44
Cp2/Qf1	72	10 R	4.57	30.02
Cp3/Qf1	60	5 YR	2.62	19.10
Cp4/Qf1	70	5 YR	3.02	24
Rc1/Qf1	76	5 YR	3.63	20

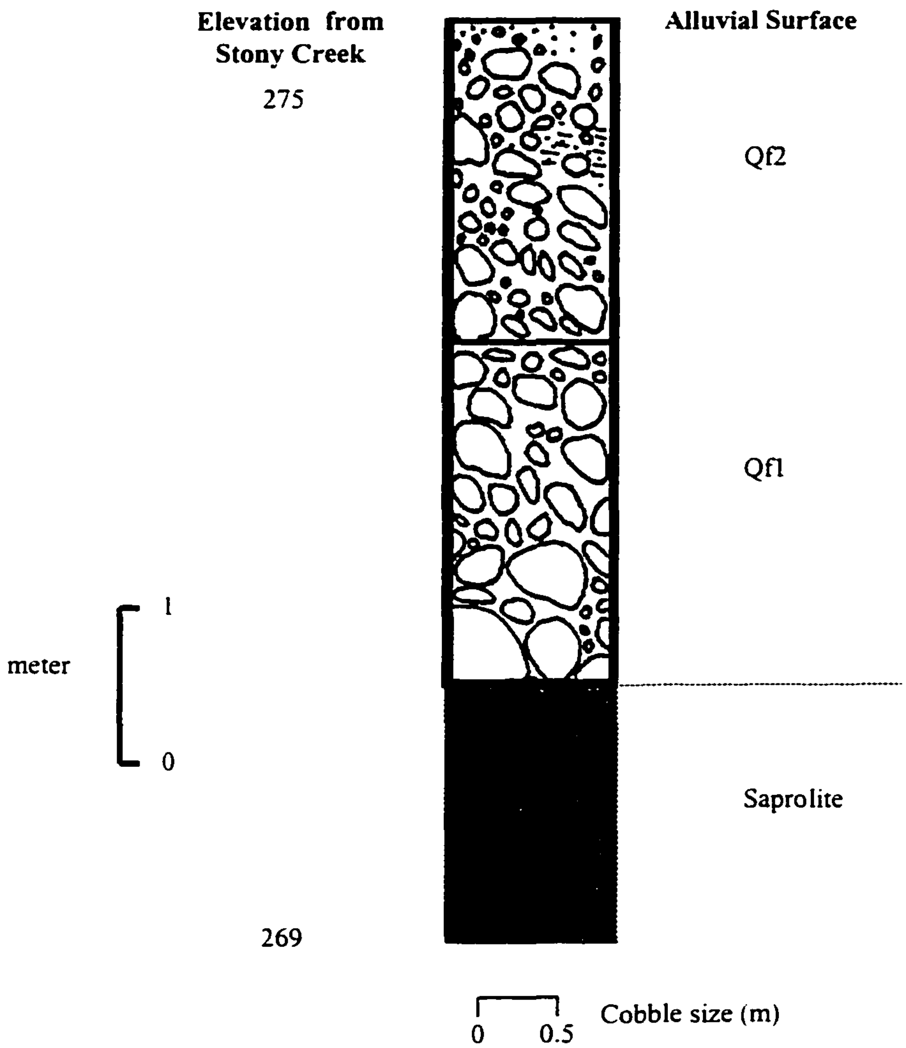
Weathering Rind Data

	Percent of Clasts		
Sample Site/Map Unit	**A**	**B**	**C**
Rec1/Qf3	100	0	0
Mid1/Qf3	100	0	0
Mid2/Qf3	97	3	0
Mid3/Qf3	100	0	0
Mid4/Qf3	97	3	0
Mid5/Qf3	100	0	0
Mid6/Qf3	100	0	0
Fd4/Qf2	0	100	0
Bw2/Qf2	0	100	0
Fd3/Qf2	0	100	0
Rec2/Qf2	0	100	0
Lv3/Qf2	0	91	9
Lv1/Qf2	0	82	18
Wat1/Qf1	0	70	30
Cp4/Qf1	0	87	13
Park/Qf1	0	60	40
A15/Qf1	0	63	37

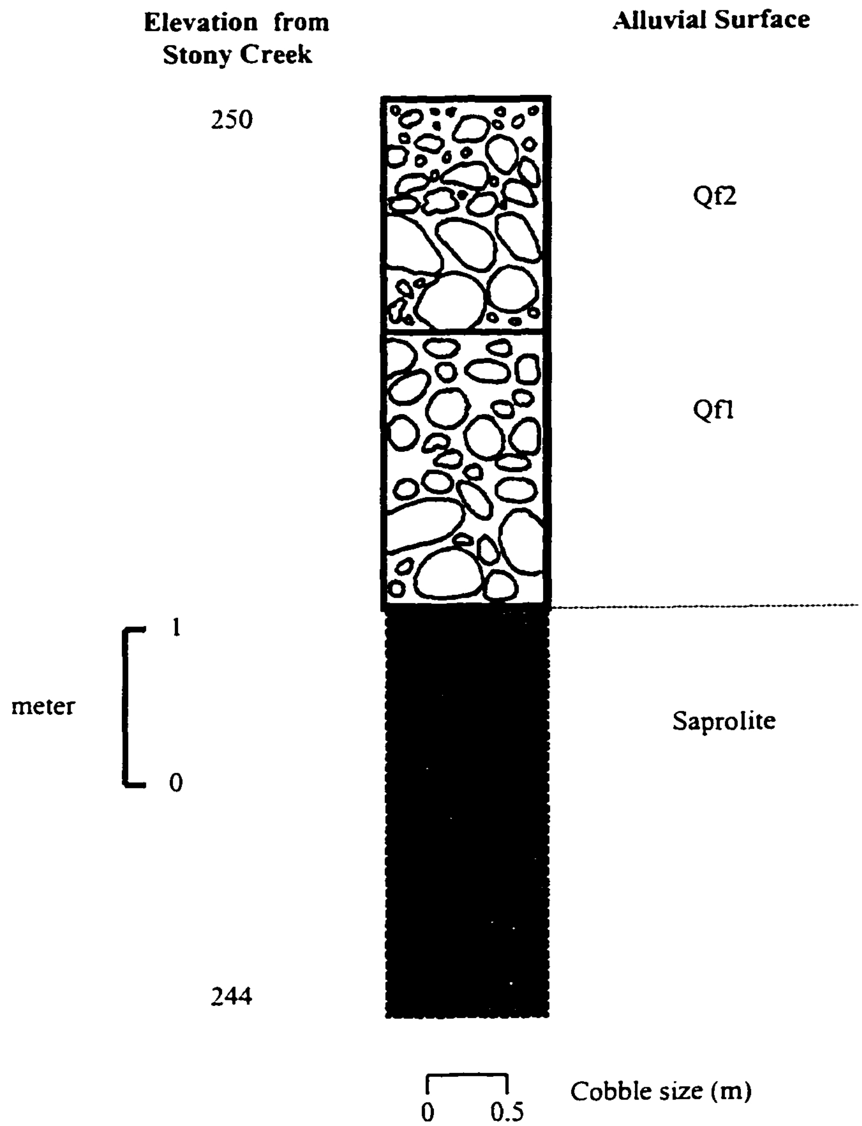
APPENDIX E

Stratigraphic Sections From Exposures Along Stony Creek

Stoney Creek Park

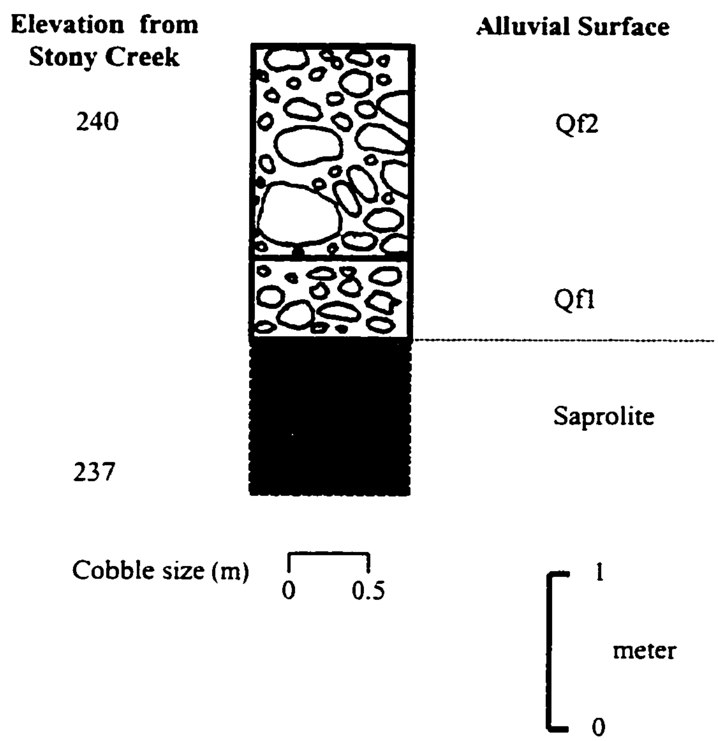


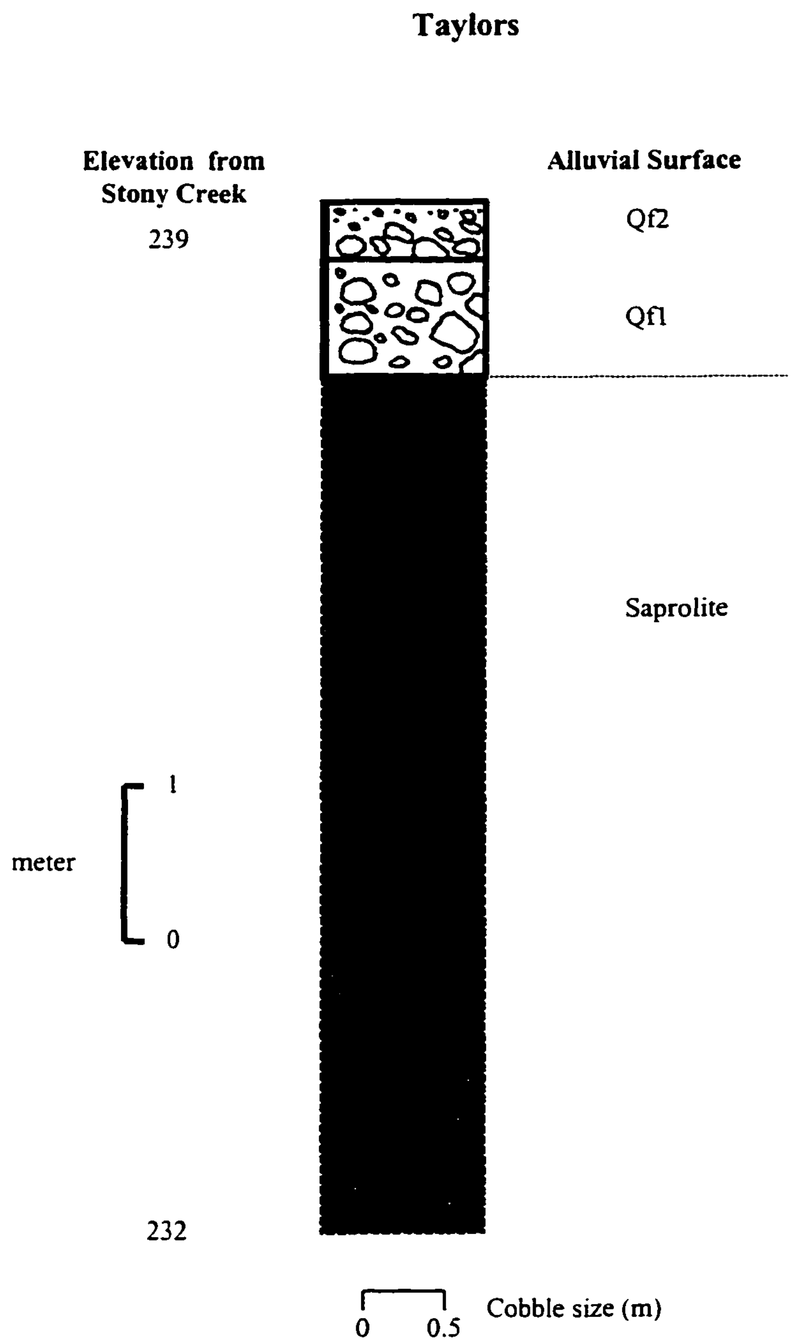
A15



Elevation from Stony Creek
Alluvial Surface
250
Qf2
Qf1
1
meter
0
Saprolite
244
0
0.5
Cobble size (m)

A24


Elevation from
Stony Creek
240
237
Alluvial Surface
Qf2
Qf1
Saprolite
Cobble size (m)
0
0.5
1
meter
0


Taylors
Elevation from Stony Creek
239
232
Alluvial Surface
Qf2
Qf1
Saprolite
meter
1
0
Cobble size (m)
0
0.5

VITA

Melinda Ann Youngblood

Education

1989-1994	Old Dominion University, B. S. Geology
1993 (Summer)	Texas Tech University System Field Camp
1995-1998	Old Dominion University, M. S. Geology

Published Abstracts –

Youngblood, Melinda A., and Whittecar, G. R. 1997. Geomorphic Evolution of an Alluvial Fan Complex, Wintergreen Virginia. Virginia Journal of Science 75th Annual Meeting.

Youngblood, Melinda A., and Whittecar, G. R. 1997. Use of Relative Age criteria to Map Alluvial Fan Deposits in Nelson County, Virginia. Geological Society of America 46th Annual Meeting Southeastern Section.